WORKSHOP ON IRRADIATION AS A QUARANTINE TREATMENT FOR FRUITS AND VEGETABLES

February 1-3, 1994

ARS-APHIS

United States Department of Agriculture

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compiled and edited[1]

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Executive Summary

The United States Department of Agriculture's (USDA) Agricultural Research Service (ARS) and the Animal and Plant Health Inspection Service (APHIS) convened a Workshop on Irradiation as a Quarantine Treatment for Commodity Protection from 2-4 February 1994, in Gainesville, Florida. Participants in the Workshop included federal and state regulatory personnel, university and government scientists, industry representatives and administrators.

The broad objectives of the workshop were to identify concerns of ARS, APHIS, States, and Industry relative to the status of the data for irradiation as a quarantine treatment, dosimetry standards, product labelling, enforcement, required doses, product quality, and the roles of ARS, APHIS, States and Industry.

Broad Objectives:

The broad objectives included:

1) Determining the feasibility of commodity irradiation, the role of irradiation now and in the future, the movement of commodities in trade and procedures needed to ensure trade.
2) Assessing what research is needed and determining where the research will be conducted.
3) Identifying potential problems and determining how such problems will be solved.
4) Defining the expectations of APHIS.

Specific Objectives:

Specific objectives included:

1) Developing methods to identify if a pest has been properly irradiated.
2) Develop procedures to identify if a commodity has been properly irradiated.
3) Develop dosimeters to ensure that pests and commodities were properly irradiated and received the correct minimum/maxium dosages.
4) Developing labels to identify:

- Where the commodity originated.
- What company owns the commodity.
- Where the commodity was irradiated.

5) Establishing and enforcing quality assurance/quality control guidelines.

6) Identifying countries willing to participate in irradiating commodites for export and identifying countries willing to accept irradiated commodities.

7) Identifying which commodities are suitable for irradiation from each participating country.

The Workshop consisted of an introduction given by Dr. Mary Carter, Area Director, South Atlantic Area; objectives and charges were given by Dr. Ken Vick, ARS National Program Leader, Quarantine; and Mr. Mike Shannon, Assistant Staff Director, APHIS, PPQ, Operation Staff, discussed the APHIS policy on irradiation as a quarantine treatment.

ARS and APHIS acknowledged that existing data are suggestive for a generic dose for fruit flies, but additional review of the data is needed before a determination can be made. Regarding a generic dose for insects other than fruit flies, more research is needed.

**Important
Points Made During
The ARS/APHIS Workshop on Irradiation as a
Quarantine Treatment For Fresh
Fruits and Vegetables**

- APHIS looks at irradiation very positively as a potential solution to quarantine problems.

- FDA has been able to determine in a number of instances that there is a reasonable certainty of no harm to the public from consumption of foods treated with ionizing radiation for achieving certain technical effects.

- FDA has determined that radiation of food at doses not to exceed 1 kGy for the purpose of disinfestation of arthropod pests is safe. Therefore, it is safe for use as a quarantine treatment as long as the 1 kGy limit is not exceeded. Whether irradiation is appropriate for a particular food must be determined on a case-by-case basis to ensure that food is radiation-tolerant for the absorbed dose range that would be required for treatment of the target pest. The use of proper dosimetry is critical for establishing compliance with regulations and that the desired technical effect has been achieved.

- Honeybee colonies infested with American foulbrood disease must be destroyed by burning to eliminate the disease. Irradiation is now recognized as an adequate treatment for American foulbrood disease, and honeybee colonies which have had the honey removed can be treated in this manner.

- Irradiation may be a viable option for treatment of sweet potatoes for quarantine treatment of the sweetpotato weevil.

- The consensus reached recently by committee members representing the Hawaiian State Planning Office, the Department of Agriculture, other state agencies, and several industry groups was that Hawaii should pursue radiation technology in the next few years. Tentative work plans include:

  a) initiating planning of a pilot irradiator facility by specifying requirements, needs and criteria, and at the same time seeking input from irradiator manufacturers for their ideas;

  b) seeking funding both at the federal and state levels for the irradiator by exploring the possibility of a Hawaii/USDA point venture for a shared facility for research and development;

  c) constructing a pilot irradiator best suited for multi-purpose use by gaining support of potential user groups in the state; and

  d) preparing plans for the management and utilization of the facility phases of test marketing of Hawaii-grown products.

- A generic dose for fruit flies, 150 Gy, would suffice for B. tryoni, B. Jarvisi, and the Anastrepha spp. studied. There are some data indicating that 150 Gy may not prevent 99.9968% emergence of normal appearing adults at the 95% confidence level for C. capitata, B. dorsalis, and B. cucurbitae.

- A generic dose of 300 Gy for all arthropods other than fruit flies should not be recommended considering the variation in arthropod types and life stages that are quarantined and the results of certain studies.

- Some of the irradiation treatments have no deleterious effects on the condition and quality of some commodities and cultivars. However, injury can occur at times with approved treatments under commercials conditions. It is important that treatments developed under laboratory conditions be feasible in a commercial setting. The treatment protocol must include not only the variability in commodity conditions, but also treatment variations which occur under commercial conditions without leading to commodity damage or insect survival.

OPENING REMARKS

by

Dr. Mary E. Carter
Area Director
South Atlantic Area
Agricultural Research Service
U.S. Department of Agriculture
Athens, Georgia

Dr. Ken Vick
National Program Staff
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Maryland

Mr. Mike Shannon
Assistant Staff Director
Operations Staff
Plant Protection and Quarantine
Animal and Plant Health Inspectionn Service
U.S. Department of Agriculture
Hyattsville, Maryland

Dr. Mary Carter
Area Director
South Atlantic Area
Agricultural Research Service
U. S. Department of Agriculture
Athens, Georgia

Jennifer, I think you and Dr. Ken Vick have done a marvelous job. I think you over estimated your support and have us pretty well packed in so we can't escape very quickly which I think is appropriate. We now know what the fruit feels like as it goes through the accelerator, but anyway I do appreciate the effort that has gone into arranging this workshop, and I'm pleased with the interest that is shown by the number of attendees at this meeting.

I have only two points that I would really like to make to you this morning and I think that you will all support what I'm about to say. I want to emphasize as we go through this workshop that we make sure that we are talking about the use of good science and good scientific data. What we need to address is research gaps or knowledge gaps which should be researched. What is important is how we interpret the data from those areas which we researched. We are going to basically be doing this for some policy makers in this country and other countries around the world, and it's very important as scientists that we do good science, that we generate good data, and that we interpret it properly so that we can have our policy makers making the appropriate policy decisions that will protect agriculture, not only in the United States, but and other countries around the world that promote trade. I think this is very important.

The other point that I think I would like to make this morning for all of you, and some of you perhaps have already had some experience with this, and this is, be sensitive to how you communicate what you are doing, particularly to the media. The way you communicate to the media will have a great deal to do with how they in turn communicate to the public. One of the things that we have experienced in many areas of science of course is the way that media interprets scientific data when they, in turn, try to communicate through their vehicles, whether it be newspapers or the radio or television, on the impact that it (irradiation) has on the public and their perceptions of what is safe, what is good, and what is wholesome.

So if you are ever in doubt as to how you should communicate, it might be almost be better that you don't attempt to communicate. I don't know. I will leave that to some other people as to how you communicate, but I do feel that communication with the media is also exceedingly important and that it should be done properly. We should make sure that the facts which we present to them should be, once again, good data, communicated in layman's language and in this way I think we will be building the kind of support that we would want for this type of quarantine activities within the boundaries of our respective states, countries, or whatever.

So, with just these few words of concern let me welcome and say that I look forward this meeting. Thank you.

Dr. Ken Vick
National Program Staff
Agricultural Research Service
U. S. Department of Agriculture
Beltsville, Maryland

I am very pleased to see all of you here this morning. I want to extend my thanks, to Jennifer, especially, for doing such a great job at organizing this workshop. As the somewhat distant local arrangements person, doing this from Miami, it was no easy job. Dr. Carter, thank you for allowing us come to the South Atlantic area. I am pleased to see you here to discuss commodity irradiation, the role of irradiation, and the movement of quarantine commodities in trade. I do want to thank you for coming.

Radiation, for decades now, has been touted as an ideal commodity treatment to prevent the spread of injurious insects on the trade of commodities. There is no dispute that irradiation is effective in sterilizing insects if a sufficient dose is applied, and many, if not most, commodities will tolerate the minimum doses that are required. There are many published research accounts for many pests and commodities that attest to this. However, the reality is that after a lot of research and talk about the promise of irradiation, there is not a single quarantine commodity presently being moved into or out of the United States (U.S.) as the result of radiation treatment. It is this fact that caused me to convene this workshop.

As I am sure most of you know that the U.S. has a Clean Air Act which requires chemicals which have potential for depleting the ozone be banned from the U. S. Methyl bromide (MB) has been identified as such a chemical, and the U.S. Environmental Protection Agency (EPA) has announced that MB will be banned by January 1, 2001. MB has been the world's leading fumigant for fresh commodities since the ban of ethylene dibromide (EDB) in the mid-eighties. The effect on U.S. exports and imports, particularly fresh commodities, will be extremely great unless alternative quarantine treatments are found. Mr. Espy, the Secretary of Agriculture, has indicated in news accounts and in various documents, that research to develop MB alternatives are among the highest research priorities for the U.S. Department of Agriculture.

This workshop is the latest of several meetings and workshops Agricultural Research Service (ARS) has organized and participated in to determine research priorities to find manageable alternatives. With limited resources, it is imperative we identify critical research gaps and real bottlenecks that keep this technology from being used and determine the best research approach to solve the problems. I am optimistic that discussions here will lead to ways to resolve some of these concerns.

It is critical that our research be focused on the real problems. We have assembled the right people who can identify the real problems. Of course, there are really two components to the radiation issue---one is research and the other is regulatory.

The Animal and Science and Health Inspection Service (APHIS), has responsibility for establishing quarantine regulations, including approval and certification of quarantine treatments. ARS works with APHIS to provide research support for this APHIS responsibility. APHIS has been a full partner in planning this workshop. The four organizing committee members, two of them were from APHIS. APHIS contributed money and has sent a contingent of high level officials to participate. They are prepared to discuss the technical needs relative to approval of irradiation as a quarantine treatment where applicable.

APHIS will make a presentation tomorrow which will give the APHIS perspective. Shortly, I would like Mike Shannon to make a few comments at the out-set of this meeting to identify some APHIS concerns that we can keep in mind as the discussions proceed. The areas of concern are indicated in the agenda. We have covered most of them. Some technical issues are not specific and may not be readily apparent in the agenda, but concerns exist, for example, will insects be required to be dead in or on a commodity? Or, can the threshold be that the insect does not emerge as an adult from the commodity? Or if it emerges as an adult, that it will be incapable of flight and unable to get into traps.

These kinds of issues are going to be critical toward implementing a quarantine treatment based on radiation, and we have to have the full support of our partners in the states that are affected by fruit flies; for instance, without concurrence from California, Texas, Florida and other states that stand to be severely impacted by introduction of fruit flies, it is going to be very difficult to implement quarantine treatments unless they buy into the treatment technology. We can all be assured that we will have the proper quarantine security guard that we are proposing.

With that I would like to introduce Mike Shannon, who is the Assistant Staff Director for the APHIS Plant Protection and Quarantine (PPQ) staff in Hyattsville. He will make a few comments on the APHIS perspective.

Mike Shannon
Assistant Staff Director
Operations Staff
Plant Protection and Quarantine
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Hyattsville, Maryland

Thank you Ken and, thank you ARS for giving lift-off to this important meeting. I want to thank all of you for being here, because nobody can figure this problem out by themselves. We can all figure it out individually, but we will not come up with the same answers. APHIS and other plant health organizations throughout the world, some of whom are represented here today, have a mandate to exclude pests and diseases, as well as a mandate to facilitate the exports from those affected countries. Those two issues are very closely linked and present very similar types of problems that technology and science must address. What is the type of activities which that kind of mandate requires of import control treatments and requirements for the entry of products to taking actions on export commodities to allow market access into foreign markets to meet other countries' phytosanitary requirements? The involvement in trade negotiations to gain market access is something that we are extensively involved in. These kinds of activities are becoming more and more complex, and, although the loss of MB can be seen as a kind of "bell-weather thing", we need more alternatives.

APHIS looks at irradiation in a very positive way as a potential solution to quarantine problems. The question before us here in the next few days is what are those problems and what is the context in which they must successfully be resolved? We are going to try to talk from the APHIS side here, since APHIS takes this technology and transfers it into a solution, and the solution is that products can move freely between countries. So our problem then becomes, how do we transfer technology so that we can reach our goals? This is becoming more and more complex. The loss of technology such as EDB and MB are two examples, but they are not the only things that affect this, and it is not just fruit flies that are the agents at issue here.

From our viewpoint, import regulations of our trading partners are becoming more and more restrictive and more and more focused on different types of pests. You are aware that GATT, General Agreement on Tariffs and Trade, and NAFTA, North American Free Trade Agreement, will imposed standards on countries on how they make quarantine decisions and how they manage their private sanitary requirements. These two agreements will raise quarantine issues to political/policy levels that we have not previously experienced, i.e., highly visible levels. This balance now speaks to the need that Dr. Carter mentioned for these activities be soundly grounded in science.

In addition, the U.S. is finding, from our perspective, a more competitive situation for access for agricultural products from foreign markets. There is more competition going on from other countries. So, this is an issue of managing phytosanitary regulations. It is becoming more complex. All countries, particularly in the U.S., find additional technological options for managing phytosanitary constraints and free trade. Irradiation appears to be an option. The question is how do we identify and agree on what the problems are and what constitute their solutions? That is not something that APHIS can do by itself or ARS can do by itself, or any of you can do by yourselves. We could all identify the problem a different way.

This kind of forum is critical to us in that it represents a broad array of people who have and see this problem in different ways. So, we can mix these things together, identify barriers and come up with the strategies that move us forward. In reviewing the files, and I am not particularly conversive in this area, radiation has been kind of in a stall for a while, and we need to change that. We are going to do what we can and, we are going to start here. Our expectations are, and, in summary, to listen to your proposals, what the barriers are to these applications, and what strategies are there to overcome such barriers. APHIS has a positive attitude, and we need this type of a forum to begin to move forward. Thank you.

IRRADIATION AS A QUARANTINE TREATMENT: THE ROLE OF THE US FOOD AND DRUG ADMINISTRATION

by

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IRRADIATION AS A QUARANTINE TREATMENT: THE ROLE OF THE US FOOD AND DRUG ADMINISTRATION

Paul M. Kuznesof, Ph.D.

INTRODUCTION

Quarantines are used to minimize the risk of transfering pests (e.g., insects, microbial pathogens) across political or geographical boundaries and are implemented for both public health and economic reasons. Quarantines of imported food stuffs are used to protect local agriculture and food production while simultaneously facilitating international trade. The consumer also benefits through access to new or competitively priced food stuffs.

Treatment of some food commodities with ionizing radiation for quarantine purposes has been recognized for a number of years as a viable and sometimes desireable alternative to the more traditional means using chemicals (e.g., methyl bromide, phosphine), cold treatments, heat treatments or combinations of these treatments for insect disinfestation. Irradiation treatments are short term (possibly resulting in added shelf life), do not result in residues of fumigants, and reduce opportunities for reinfestation if treatment consists of irradiating the packaged food. Food commodities, however, differ in their relative tolerances to ionizing radiation and ionizing radiation can in some instances be detrimental, for example, by adversely affecting wound-healing ability, increasing the rate of tissue darkening, and increasing susceptibility to post-harvest pathogens. Thus, not all commodities are suitable candidates for radiation treatment.

The purpose of this paper is to outline the basis of the US Food and Drug Administration's (FDA) authority to regulate the treatment of foods with ionizing radiation and the agency's responsibility for establishing the safe uses of ionizing irradiation, and to summarize the current regulations for food irradiation as they pertain to the quarantine treatment of foods.

FDA ESTABLISHES THE SAFE USE OF IONIZING IRRADIATION

For ionizing radiation to be used as a quarantine treatment for foods, there must be an applicable food additive listing in Title 21 of the *Code of Federal Regulations* (CFR). This is so, because the US Congress in its 1958 amendment to the *Federal Food, Drug, and Cosmetic Act* (the Act) recognized a source of radiation to be an incidental food additive used for the process of irradiation. Thus, Section 201(s) of the Act defines a food additive, in part, as:

"... <u>any substance</u> the intended use of which results or may reasonably be expected to result, directly or <u>indirectly</u>, in its becoming a component or otherwise <u>affecting the characteristics</u> of any food (including ... any <u>source</u> of radiation intended for any such use, ...". (underlines added)

Section 409 of the Act stipulates that a food additive must be shown to be safe under its proposed conditions of use <u>before</u> its use can be regulated. To obtain a regulation in the proposed conditions of use before its use can be regulated. To obtain a regulation in the CFR, a petition must be submitted to FDA for pre-market approval. The petition must contain sufficient information and data to allow FDA to conclude that the additive is safe for its intended use. Only then will a regulation be issued.

Understanding the meaning of "safe" and "safety" is critical to the success of the petition review process. For, without a rational definition, the ability for regulatory decision-making would not exist. The following definition is given in the CFR (21 CFR 170.3 (i)):

> "*Safe* or *safety* means that there is a reasonable certainty in the minds of competent scientists that the substance is not harmful under the intended conditions of use. It is impossible ... to establish with complete certainty the absolute harmlessness of the use of any substance." (underlines added)

Thus, FDA has been able to determine in a number of instances that there is a reasonable certainty of no harm to the public from consumption of foods treated with ionizing radiation for achieving certain technical effects.

FDA REGULATIONS FOR IONIZING RADIATION

21 CFR 179.25 - General Provisions for Food Irradiation
The so-called "Omnibus Rule" on food irradiation published in the *Federal Register* in 1986 (51 FR 13376-13399, April 18, 1986) codified "Good Irradiation Practices" in 21 CFR 179.25. To summarize, first, firms treating food with ionizing radiation shall adhere to the requirements of 21 CFR 110 concerning current good manufacturing practices for food processing and food production. Second, food shall be treated with the minimum absorbed dose necessary to accomplish the intended effect and not more than the maximum dose specified by the applicable regulation. Third, packaging materials subjected to irradiation incidental to the irradiation of the food shall comply with 21 CFR 179.45. Fourth, treatment shall conform to a scheduled process, i.e., there must be written documentation that the radiation dose range is appropriate for the particular application. Fifth, the scheduled process shall have been prepared by a qualified individual, one who has "expert knowledge" in the irradiation of food and of the specific food and the irradiation processor's facility. Sixth, detailed records must be kept and maintained.

Record maintenance is critical to FDA's ability to enforce its regulations. According to 21 CFR 179.25, records must include at a minimum, the food treated, lot identification number, date of treatment, the scheduled process, evidence of compliance with the scheduled process, a description of the radiation source, information on source calibration, dosimetry procedures, and the absorbed-dose distribution in the irradiated food. All records shall be available for inspection and copy.

ASTM Standards

Of particular importance in complying with 21 CFR 179.25 is the need for documentation of dosimetry procedures and the absorbed-dose distribution in the irradiated food. A number of Standard Guides and Practices developed by ASTM Subcommittee E10.01 on Dosimetry for Irradiation Processing that address dosimetry have now been published. Although not codified in the CFR, these documents are worth mentioning because they help define the meaning of "Good Irradiation Practice" and can be of considerable use to processors of irradiated foods, as well as to government inspectors and rulemakers. Three "umbrella" documents are worth noting:

E1204 - Practice for Dosimetry in Gamma Irradiation Facilities for Food.

E1261 - Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing.

E1431 - Practice for Dosimetry in Electron Beam and Bremsstrahlung [x-rays] Irradiation Facilities for Food Processing.

Two umbrella standards currently under development that are also of great interest and importance are:

1) Guide for Estimating Uncertainties in Dosimetry for Radiation Processing.
2) Guide for Dose-mapping Product in Radiation Processing Facilities.

One other ASTM standard,

F1335 - Guide for Irradiation of Fresh Fruits for Disinfestation as a Quarantine Treatment.

developed by ASTM Subcommittee F10.10 on Food Processing and Packaging, has as its focus the handling and treatment of the fruit rather than dosimetric procedures and should be a useful adjunct to the dosimetry standards.

21 CFR 179.26 - Ionizing Radiation for Treatment of Foods

This regulation has three parts: 1) a list of the sources of radiation that are permitted for treatment of food (cobalt-60 and cesium-137 isotopes for gamma irradiation; machine sources for the production of electron beams (< 10 Mev) and x-rays (< 5Mev)); 2) a list of the foods permitted to be processed by irradiation, along with the technical effect and maximum permissible dose; and 3) labeling requirements. The listing for the treatment of food for arthropod disinfestation (maximum dose < 1 kGy) was promulgated in the Omnibus Rule of 1986. In addition, 21 CFR 179.26 currently allows the use of ionizing irradiation on fresh pork (trichina control, 0.3-1 kGy); on fresh foods (growth/maturation inhibition, < 1 kGy); dry or dehydrated enzyme preparations (microbial disinfestation, < 10 kGy); dry or dehydrated aromatic vegetable substances (microbial disinfestation, < 30 kGy); and fresh or frozen poultry (pathogen control). The regulations for treatment of fresh foods for growth/maturation inhibition and of aromatic vegetable substances for microbial disinfestation were also subjects of the Omnibus Rule.

FDA's rationale for concluding that the treatment of foods with ionizing radiation is safe for arthropod disinfestation (and for the other two companion applications) is discussed at length and in detail in the preamble of the Omnibus Rule. In reaching its conclusions, the agency addressed the issues of induced radioactivity, nutrient destruction, formation and types of radiolytic products, consumer exposure to radiolytic products, selective destruction of microorganisms, record keeping, and labeling. The agency also summarized its evaluations of a large body of toxicology studies.

The FDA recognizes the possibility that in some cases the disinfestation of arthropod pests by radiation treatment might require absorbed doses above the currently permitted level of 1 kGy. For example, if the minimum effective dose were 0.8 kGy, it would be extremely difficult, if not impossible, to achieve a dose-uniformity ratio of less than 1.3 to assure that the maximum permitted dose is not exceeded. For such cases, a petition to the agency to amend the regulation would be necessary. Such a request could be narrow, i.e., to allow a higher dose for the specific commodity, or broad, i.e., to increase the permitted maximum dose for all foods. It is highly recommended for anyone considering submitting a petition to consult first with FDA to agree on the best approach.

Labeling requirements are fairly clear. Retail foods that have been irradiated require labeling as described in the regulation. Labeling is not required, however, on a retail food that has not been irradiated even if it contains an irradiated ingredient. For example, a grapefruit irradiated for quarantine treatment and sold whole directly to the consumer must be labeled as having been treated. But, if the irradiated fruit is sent to a food processor for incorporation with unirradiated fruit into a fruit cocktail that is not irradiated, the fruit cocktail need not bear labeling indicating that it contains fruit that has been irradiated. On the other hand, the regulation stipulates that food that has been irradiated or contains a component that has been irradiated must be labeled as having been so treated when shipped to a food manufacturer/processor for further processing. Thus, the manufacturer of the fruit cocktail should expect to receive boxes of grapefruit with appropriate labeling.

The requirement for labeling at the non-retail level, it is worth pointing out, alerts a food processor that further irradiation of the food may be inappropriate because of the potential for exceeding the maximum permitted dose for that food and, thereby, causing the food to be adulterated.

21 CFR 179.45 - Packaging Materials for Use During the Irradiation of Prepackaged Food

This regulation identifies those packaging materials that FDA has determined may be safely subjected to radiation incidental to the radiation treatment of pre-packaged foods. The list is limited but includes a number of materials likely applicable for irradiation for quarantine use, e.g., polyethylene and wax-coated paperboard. The primary safety concern that needs to be resolved for regulating a packaging material in 21 CFR 179.45 is the potential exposure to the consumer of the irradiated food to volatile chemicals that might be generated in the packaging material and subsequently migrate into the food. To obtain a new listing in 21 CFR 179.45 requires a food additive petition. Recently, however, the agency announced its "Threshold of Regulation" (T/R) proposal (58 FR 52719-52729, October 12, 1993) that would permit certain food additives to be used under specified conditions in the absence of a regulation, thus eliminating the burden of developing a petition to submit to the agency.

In essence, FDA has proposed to establish a process for determining when the likelihood of migration to food of a component of a food-contact article is so trivial as to be of no public health significance and not require a regulation for its use. Under the T/R proposal

information about the proposed use will undergo an abbreviated review by FDA to determine if the established criteria for a favorable decision are successfuly met. One criterion fixes a dietary concentration of 0.5 ppb in the daily diet as the threshold of regulation for migrating substances. Another is that the substance must not be a known carcinogen. So, how might concerns about migration of substances from packaging materials to food during and following the irradiation of packaged food for quarantine purposes be viewed in the light of the T/R approach?

Many of the foods that would be likely candidates for radiation treatment for quarantine purposes would be fresh fruits that possess non-edible skins or peels. These coverings may function as barriers to migration of substances released from packaging material during irradiation. The low doses (< 1 kGy) that would be used would also limit the yield of radiolytic products from the packaging. The ratio of food weight to surface area of packaging, length of contact time, and temperature during contact are also significant factors in determining the likely extent of migration and, hence, consumer exposure. Therefore, it is possible, and perhaps even probable, that the 0.5 ppb dietary threshold for any given radiolytic product would not be exceeded and obviate the need for additional petitions. As noted above, however, FDA would have the opportunity to review data and consider arguments put forth to support a favorable T/R decision.

REGULATION ENFORCEMENT

FDA is empowered by the Act to exercise its authority against adulteration and misbranding of food. The major provision in the Act addressing adulteration of irradiated food is section 402(a)(7):

> "A food shall be deemed to be adulterated ... if it has been intentionally subjected to radiation, unless the use of radiation was in conformity with a regulation or exemption

in effect pursuant to section 409 [the food additive provisions]."

The misbranding provisions of the Act are set out in section 403 and relate principally to labels and labeling. Irradiated food is not specifically mentioned. The labeling of irradiated food must conform to the rules provided in 21 CFR 179.26, as noted above.

The treatment of foods with ionizing radiation for quarantine purposes can be expected, in many instances, to be conducted on foreign soil. Although FDA, in general, can prohibit entry of irradiated foods into the USA if they appear to violate the regulations, FDA inspectors only have the authority to enter food manufacturing and food processing establishments in the USA to conduct site inspections and copy records. USDA's Animal and Plant Health Inspection Service (APHIS), however, does station inspectors on foreign soil and, thereby, has the opportunity to work closely with irradiation processors to assure that quarantine treatments with ionizing radiation are carried out in accordance with the applicable regulations.

CONCLUSION

FDA has determined that irradiation of food at doses not to exceed 1 kGy for the purpose of disinfestation of arthropod pests is safe. Therefore, it is safe for use as a quarantine treatment as long as the 1 kGy limit is not exceeded. Whether irradiation is appropriate for a particular food must be determined on a case-by-case basis to assure that the food is radiation-tolerant for the absorbed dose range that would be required for treatment of the target pest. The use of proper dosimetry is critical for establishing compliance with regulations and that the desired technical effect has been achieved.

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APPROVAL STATUS OF IRRADIATION AS A QUARANTINE TREATMENT IN FLORIDA

by

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APPROVAL STATUS OF IRRADIATION AS A QUARANTINE TREATMENT IN FLORIDA

Due to Caribbean fruit fly, Anastrepha suspensa, many Florida agricultural commodities must be treated to meet the quarantine restrictions of the receiving state or country. These commodities are certified by post harvest treatment which include: cold treatment, hot water treatment or fumigation. Florida citrus can also be certified from designated production areas which are maintained free of caribbean fruit fly infestation.

In addition to concerns about Caribbean fruit fly, Florida blueberries must be fumigated to meet California quarantine restrictions for plum curculio weevil and blueberry maggot.

The following Florida commodities are currently treated to meet quarantine restrictions: blueberries, carambola, grapefruit, guava, mango, orange, and tangerine. These commodities are treated for the following destinations: Arizona, Bahamas, Bermuda, California, Hawaii, Japan, and Texas. There are potential markets for some of these commodities in Australia, Chile, Korea, Mexico, and Thailand. There is a lot of potential in Florida for alternative treatments to the ones currently available. Methyl bromide is in jeopardy of cancellation by the year 2001. Cold treatment currently must be accomplished on board ship in transit. This is acceptable for some distant markets, but it is not feasible to use it for countries which are closer or for domestic shipments.

One attempt at an on-shore cold treatment facility was made, but it did not prove cost effective nor was the facility adequate to maintain constant temperatures. Also, not all citrus production areas qualify for fly-free status, and the fly-free program is very expensive for growers.

Irradiation would be cost effective, and there are two facilities in the state of Florida capable of treating the commodities: The Florida Linear Accelerator here in Gainesville which is operated by this department and the cobalt unit which vindicator operates in Mulberry.

The USDA approved irradiation as a regulatory treatment to certify products to meet quarantine restrictions in 1987; and the dosage rates have been developed for some commodities such as grapefruit and mango. Shortly after the USDA approved irradiation, the Caribbean Fruit Fly Technical Committee, which gives the Division of Plant Industry guidance on issues relating to Caribfly, asked the USDA, as part of the annual bilateral talks with Japan, to attempt to gain Japanese approval for irradiation treatment. Following negotiations, the committee was advised that Japan indicated they are not ready to consider such treatments. Efficacy was not the issue, but irradiation treatment as a concept was not evidently accep ..e to them.

The next largest ..et for citrus treated for Caribfly is California. Negotiations for commodity treatment rest between this department and the California Department of Food and Agriculture. A couple of years ago, a letter was drafted to California which would have asked them to approve irradiation for Florida grapefruit. This was prompted by interest on the part of the Florida gift fruit shippers who must currently fumigate fruit for these markets. Some how word of this possibility leaked to the news media and resulted in a flurry of press. The gift fruit shippers withdrew their interest stating that the citrus industry had no desire to be pioneers in this area because pioneers ended up with arrows in their backs.

Since that time the Division of Plant Industry has had a number of individuals inquire about having irradiation approved as a quarantine treatment for California or one of the other citrus producing states. The Division's standard response is that a formal request can be made once Florida Citrus Mutual writes us and requests that this be done. Such a request has yet to be received.

One last note concerns honeybee colonies. Currently honeybee colonies infested with American foul brood disease must be destroyed by burning to eliminate the disease. Irradiation is now recognized as an adequate treatment for American foulbrood disease, and honeybee colonies which have had the honey removed can be treated in this manner.

QUESTIONS, ANSWERS, COMMENTS AND DISCUSSION ON CONNIE RIHERD'S PRESENTATION

Question: I am interested in the sweetpotato weevil problem. Is that a problem in Florida, and do you see irradiation as appropriate for that problem?

Speaker: I think it would be, and I really have not thought about sweet potatoes. We do occasionally have a market for sweet potatoes, and in states or countries that have quarantines against sweetpotato weevil, the sweet potatoes must be fumigated. So, yes, irradiation would be an appropriate quarantine procedure.

Comment: I used to work at J. L. Brooks, and they sold a lot of sweet potatoes but were never allowed to sell them in most of the southeastern states and particularly in California. These were white flesh potatoes that are picked fresh or harvested fresh and not cured. Many of the customers did not want them if they were fumigated, because they them fresh and inorder to fumigate, they had to be cured; fresh sweet potatoes could not tolerate fumigation. So, I think that irradiation would be very attractive for treatment. The commodity is particular attractive to Hispanics, so California would be a tremendous market for them. There have been no alternative treatments, so I thing the viability for irradiation is a good one.

Speaker: I had not thought of it either.

Comment: We are currently conducting a study on irradiation of sweet potatoes. As for a quarantine treatment for the sweetpotato weevil, we have pretty much worked out the doses. For example we know the doses for killing the egg stage, the three larval stages, and for the pupae. We will have all these with data available and expect to get it published within the next year. The problem, though, is the weevil itself. The adult can stay in the sweet potato, and the adult is the most resistant stage to irradiation. The weevil may stay in the root for 7-8 days, and when it comes out, it's ready to mate; that's the problem that we have to deal with. Now, there are normally certain sanitized fields where you have integrated pest management systems and where there are a lot of the sweetpotato weevils anyway, so you are going to have only eggs or first instars; these can be treated with irradiation. These are just some of the problems with sweetpotato weevil.

Comment: For the benefit of non-Americans, would you clarify the relations between Federal and State quarantine?

Speaker: Yes, its a cooperative effort for the export of our commodities to foreign markets. Of course, for inter-state shipments, that are regulated by the state departments of agriculture. For the shipment of commodities to international markets, these are normally, cooperative certification programs between the states and the federal government since the states have the most inspectors.

Question: When would the Federal government not be involved?

Response: In negotiations between the various states about quarantine restrictions where Federal Quarantine is not involved. That's all.

PPQ Comment: When the pest is introduced, and of limited distribution in the U. S., certain of those that are of common concern to the states, are regulated under Federal regulations to prevent their spread, for example Gypsy moth and pests of that nature. Once they become distributed through a large portion of their range, or if they are not by mandate for Federal regulation, then states are free to impose their own regulations to protect their interests from other states. When meeting the phytosanitary requirements of other countries, however, that is what the Federal government is supposed to do on behalf of the interest of the states.

Question: You mentioned there were one or two treatments that were not cost effective. Define cost effective.

Speaker: I think that irradiation, cost-wise, is comparable with other treatments. The process that is costly for our growers is our fly free certification program, which is not a treatment and is a costly undertaking.

Comment: Connie, may I comment on George's question? Based on my transportation experience, carrying cold treated Florida grapefruit to Japan, for example, you don't know until you arrive in Japan whether or not you have succeeded with the cold treatment protocol. If you don't succeed, it is up to the owner of the goods and the steamship line to share the additional expense of disposing of those goods by dumping in the sea, by taking them to another country, or even by returning them to Florida. That is where it gets overwhelmingly costly.

Speaker: Cold treatments are comparable in cost to what it would cost for commodities to be irradiated.

Comment/Question: Just a clarification from my concept, your policy as you described it in the state of Florida if a grower or shipper or someone from citrus business, requested help in establishing irradiation as a quarantine treatment, would you refuse them unless one of the two or three organizations that the state recognizes to submit the request?

Speaker: Yes, we have had some individuals talk to us, and we suggest that they go to their industry organizations, most of them know them, and gain support, and we never hear back. I think the industries are waiting until they feel that they have consumer acceptance.

Comment: In my opinion, you are not going to get consumer acceptance.

Speaker: Well, I think that there are some products on the shelves, and I think that as it is accepted for other commodities, the citrus industry here will probably embrace that technology. They said they did not want to be pioneers, that was their position, but I think that with the many food safety issues that have surfaced and the fact that irradiated strawberries received very good consumer acceptance....all of these things will lead eventually to acceptance of the process.

Comment: I think you are not going to get demand until it is on the shelf.

Comment: Just a comment on the way we might be able to bridge that gap. We can conduct some pilot projects where a limited amount of citrus, for instance, is fumigated or irradiated and then moved to a specific market. If there is no major problem, then the focus should be for more wider use and acceptance.

Speaker: Well, I am commenting on the position of the citrus industry. We will wait until they request it, because of the bad press it can cause. A couple of years ago, they did not want the false impression that all citrus products in Florida were irradiated, and they were concerned that detractors would try to make people believe that. So they are very concerned about their market and concerned about selling Florida products, and we have to be aware of such concerns.

Comment: I can understand the sensitivity, but when the question is consumer demand for the product, how many consumers are demanding the product be treated with methyl bromide? How many demand methyl bromide for quarantine, not shelf life extension.

Speaker: Well, the citrus industry is concerned about their customers. They are also concerned about their customers that are buying it such as fruit wholesalers. I think when they do not have methyl bromide as an option, they will be forced into other treatment procedures such as irradiation.

Comment: A remark was made that a pilot plan might be an idea, an option, but it has been shown that when you have a pilot demonstration and that is not followed by having food routinely available on the shelf, it has a negative impact, because people become aware that irradiation took place, there is publicity about the pilot program, and then they hear nothing more about it, They cannot buy the food. They think, well, maybe there was something wrong. So, from what I hear, the best thing to do is to get food on the shelf like is being done by Vindicator's now and, somebody has to get out front and do it; and you're saying, well, by the year 1999 we are going to be in a real problem because you can't use methyl bromide, but it is too late because you can't build 50 irradiators in a few weeks and take care of the problem, you've got to think ahead of it!!

Speaker: Well, we have and that is why we have constructed a facility and Vindicator has constructed another one. Between the two facilities, I think Florida's needs can be met.

Comment: Just a follow up comment on that, I don't think I agree with what you said. If you have a problem and there is a lot of publicity, it shows that consumers prefer irradiated fruit, that opens the door for the market.

Speaker: And it certainly should be a treatment that customers will prefer over cold treatment and over fumigation.

Comment: There are still pioneers left in Florida. There's a few out there.

Speaker: Well, there are many in this state because Florida is now recognized as one of the key, if not the key, "bell-weather" state in the country. And you can look at the trends in Florida to see what is going to happen tomorrow.

Comment: Connie, with grapefruit, is there a quality benefit to irradiation over say cold treatment?

Speaker: Yes.

Commentator again: Is that obvious to the consumer?

Speaker: Yes.

Comment: How about a marketing demonstration of fresh fruit versus cold treated fruit on the same shelf, the same day, so you could see the difference?

Speaker: Certainly, I think that's an option. Right now, we do have fruit, quite a bit of fruit moving, 11,000,000 cartons of grapefruit to Japan, of that 11,000,000 cartons, 9,000,000 comes from our fly free zone, which has had no post harvest treatment and that fruit is highly preferred over any treated fruit. You can get double the price for that fruit.

Comment: And the treatment, that's just a cold treatment? Or fumigation at this time?

Speaker: At this time, it is mainly limited to cold treatment and fumigation, but we are moving a lot of fruit from our fly free production area. We are not shipping any methyl bromide fumigated fruit to Japan. That's all for the domestic market. Of the 11,000,000 cartons, up to 9,000,000 came from the fly free production areas the other 2,000,000 cartons came from cold treatment.

Comment: What do you feel the cost of irradiation has to be to be economically competitive?

Speaker: I couldn't give you a figure off the top of my head, Bill Hargraves from Vindicator's probably can.

Other commentator: Let me ask you something, Bill, would using methyl bromide as a base, is that a fair analogy for cost effectiveness simply because methyl bromide looks like it won't be here after 1999, so if you are going to compare the cost ratio, it's got to be something other than to methyl bromide, for example, to cold treatment or hot water dipping and etc. The other available quarantine treatment that we have other than methyl bromide, so, in that regard, it may be quite cost effective. Response: Yes. Comment: Now, there may be logistical problems. Cold treatment is up to about 3-5 cents per pound.

Ralph Ross: I think that is what we have to go on. And let me, if I could make one other comment, I think, this morning we talked about methyl bromide being phased out as of January 1, 2001. You know, that is approximately seven years, but I don't think we should take that seven years for granted, and let me tell the reasons why. In 1995, the Montreal Protocol will review methyl bromide again. Now at this juncture there are no regulatory controls within the Montreal Protocol for methyl bromide, but something may occur in 1995. Now, if they go for a ban sooner than the year 2001. The U.S., because of the nature of the Clean Air Act will be mandated to take similar actions to the Montreal Protocol. We can be mandated to phase out methyl bromide sooner, and there is already a movement on its way to get methyl bromide phased out within the Montreal Protocol as soon as possible. And, I think that as we go through this (exercise) we should be looking at a phasing in, not taking the assumption that on December 31st in the year 2000 will go to these other techniques.

Comment: Ralph, you are right on target and I am awfully glad that you brought that up, I was in a meeting with the EPA in Florida and the Citrus industry over ethylene dibromide in 1986, was it? And we got the year extension from EPA, what was it? three months into that year, the consumers union was so strong in Japan over the residue levels on EDB that all of a sudden we had thirty days to stop.

Ross: Another reason for making that statement, when we negotiated those regulations with EPA that just went into effect, we tried to get in writing from EPA that, two things: (1) We tried to negotiate with them, that there would be no incremental decrease in production between now and the year 2001, to which they stated in the Federal Register that it would occur, unless they got data to show otherwise and the other thing (2) that we would have methyl bromide to the year 2001, and they would not guarantee that. We received only a verbal assurance.

LINEAR ACCELERATOR IRRADIATION AS A QUARANTINE TREATMENT

by

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ABSTRACT

An irradiation facility has been completed in Gainesville, FL, utilizing a GE-CGR linear accelerator as the irradiation source in a two level design. The lower level has a one meter horn for 10 MeV electrons to irradiate shallow layers of commodities. The upper level has a 2.5 meter horn equipped to produce 5 MeV X-rays to irradiate loads up to pallet size. Automated conveyors will transport materials to be irradiated. The facility is divided for irradiated and unirradiated commodities with freezer and refrigerated storage on both sides. The facility is designed for both research and demonstration purposes and has the capacity to irradiate samples ranging in size from a petri dish to a pallet load and to utilize either electrons or X-rays. This design allows irradiation of a single tomato, packaged meat products, flats of blueberries, beehives, or pallets of citrus. With electron and X-ray capabilities, this facility provides opportunities for irradiation for quarantine treatment research and demonstration projects for interested scientists.

The industrial use of electron beam accelerators is gathering momentum. The reasons for the increase in their use vary but center around improving industrial efficiency. Antipollution legislation which restricts the use of many fumigants has created additional intrest in the use of all types of irradiation. This use restriction has been a factor in the increased intrest in irradiation as a quarantine treatment. In 1980 the U. S. Environmental Protection Agency (EPA) notified the citrus industry and agencies involved with the use of ethylene dibromide (EDB) for fumigation of citrus fruit that continued registration of EDB was not assured and that alternative certification procedures must be examined prior to extension of registration. The EPA named several alternatives and specifically stated that irradiation should be considered. This action prompted federal, state, and private industry scientists to initiate research to find alternative methods to certify that Florida citrus and other commodities met requirements for absence of insect pests and disease.

In addition to research on fly-free zones and cold treatment techniques, investigations of the use of irradiation for disinfestation of fruit were initiated in Florida. Grapefruit was the primary focus of this research due to the importance of the Japanese market. One of the first problems encountered in this cooperative effort was finding a facility to irradiate grapefruit. The units used by the USDA in Miami and in Gainesville could irradiate only 2 grapefruit at a time. Tests were conducted where grapefruit were infested in Miami and trucked to

New Mexico for irradiation and back to Florida for evaluation. Hatton et al. (1982) and von Windeguth (1982) reported promising results, even though only 8 grapefruit could be irradiated at a time. Later, Ismail et al. (unpublished data) shipped grapefruit to New Jersey and conducted dosimetry studies on irradiating a box of fruit at a time. They followed with studies in The Netherlands where 2 pallets of grapefruit at a time were irradiated with a max/min ratio of approximately 2 (maximum dose twice minimum dose).

Based on these promising results, the USDA and the United States Department of Energy (DOE) planned an irradiation facility in Miami, Florida. After the USDA withdrew from this program, the Florida Department of Agriculture and Consumer Services (FDACS) in 1984 filed an official request with DOE to be considered for an irradiator to be built next to a proposed Caribbean fruit fly mass rearing facility. After the U. S. Congress provided funds to establish regional demonstration irradiators, negotiation between DOE and FDACS led to a 1987 cooperative agreement to build an irradiation facility in Gainesville, Florida. The conceptual design utilized cesium-137 as the irradiator source, with DOE supplying the cesium. However, after General Electric purchased a French company that produced linear accelerators, the design was changed to utilize a linear accelerator to provide both electrons and X-rays for irradiation. The total federal funding for the project through the DOE was $5.4 million with additional contributions in funds, personnel, management costs, and land through the State of Florida. Smittle et al. (1991) reported on the progress and planned uses of this facility.

The linear accelerator was manufactured in France by General Electric Medical Systems - Europe. The Florida model of the CIRCE accelerator is equipped with scanning horns on two levels (Figure 1). The lower level has a one meter horn producing electrons up to 10 MeV at 10 kw to treat shallow layers of commodities. The upper level has a 2.5 meter horn producing X-rays up to 5 MeV at 15 kw to treat large cartons or pallet loads of commodities. A switching magnet is used to control the use of either scanning horn. Automated conveying systems are installed to transport commodities on both levels. The upper conveyor uses a tow-chain system to transport carts holding 4 X 4 X 6 ft pallets into the irradiation chamber and past the X-ray beam. An automated system rotates the carts 180° after the first pass and the carts pass through the irradiation chamber again to provide irradiation from 2 sides. The lower conveyor uses belts, rollers, and a stainless steel chain system to move cartons under the electron beam. This system allows cartons up to 18 inches high and 36 inches wide to be irradiated.

The facility has over 13,000 sq ft including the lower irradiation area and a mezzanine equipment area. The shield area utilized over a million pounds of concrete and over 50,000 lbs of steel. The wall separating the linear accelerator from the operations area is almost 10 ft thick. The outside walls of the shield are

2 ft thick and the roof is 3 ft thick. The entire shield area is covered with 15 ft of soil to provide adequate shielding for the X-rays. A 70 X 102 ft metal building provides space for the equipment and operations area. The majority of the area is open to provide space to store and handle pallet loads of commodities. The area has an 8 ft high chain-link fence down the center, dividing the space into areas for irradiated and nonirradiated commodities. Both areas contain freezer and refrigerator space. This area also contains the control room, dosimetry laboratory, manager's office, shipping office, and rest rooms. The versatile design allows application to a host of agricultural commodities and meets processing requirements for foods as well as non-food items. A loading dock is accessible through large overhead doors. This design allows large transport trucks to unload commodities on the nonirradiated side; the commodities are then loaded onto the conveyor system and transported through the shielded labyrinth for irradiation. Irradiated products exit into a separate product section where additional freezer, refrigeration, and docks are provided.

The facility is complete and operating. It is located next to the Caribbean fruit fly mass rearing facility at the Division of Plant Industry Headquarters in Gainesville, FL. Preliminary comparison tests of electrons and gamma rays on Caribbean fruit flies produced comparable results. Currently it takes over 5 minutes to irradiate 750 ml (about 39000) Caribbean fruit fly larvae. With the linear accelerator, trays containing over 7500 ml can be given a dose up to 50 kilorads (500 gray) in one second as trays pass under the beam at 60 ft/min. Since it takes 3.25 minutes for the tray to pass on the conveyor from load to unload positions, 50 trays (over 20 million larvae) could be irradiated in less than 5 minutes. Following additional testing, larvae for the Caribbean fruit fly parasite release project will be irradiated daily using the linear accelerator. Miller etal (1994) reported on the effects of irradiation of blueberries using electrons with doses up to 125 krad. Further tests are planned for this year in an attempt to provide more data for approval of irradiation as a quarantine treatment for blueberry insect pests. Blueberries are grown in this area and The Division of Plant Industry fumigates blueberries for local growers to provide quanantine certification for shipment to other states. Last year a local grower brought 200 flats of blueberries to be fumigated. The fumigation treatment using methyl bromide took about 6 hours at room temperature. Treatment using electrons would have taken less than 10 minutes and the blueberries could have been kept refrigerated during treatment. This 200 flats had a value of $8000 at the packing plant last year and in recent years the value has been much higher. This is an example of how approval of irradiation as a quarantine treatment can benefit a small farmer.

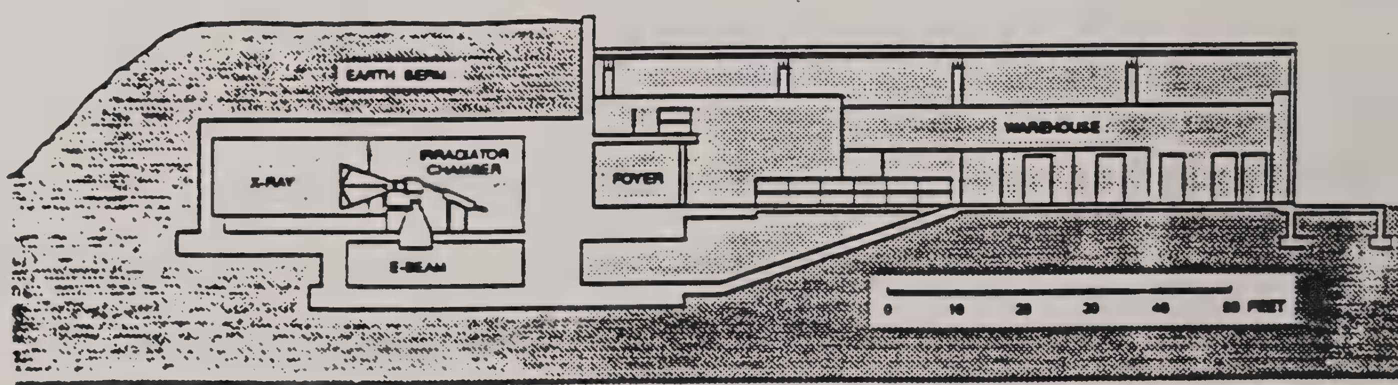
Oranges and grapefruit as well as other citrus are grown on over 700,000 acres in Florida with over 23 million boxes going for foreign export plus shipments to other citrus-producing states, all of which require quarantine treatment for insect pests. USDA has approved irradiation as a quarantine treatment for specific insect pests on specific citrus products. Dr. Ismail at the Florida Department of Citrus and Dr. Sharp's group at USDA in Miami have data on the effect of irradiation on many more varities of citrus. The irradiation dose needed to prevent adult fruit flies from emerging from irradiated larvae is well documented, thus it appears that approvals could be extended to many more products.

The Florida linear accelerator can be used to produce X-rays for irradiation of pallets of citrus or other commodities. X-rays and gamma rays produce comparable results in insect pests, but dose mapping studies are necessary for each irradiator and product.

Agricultural products other than food products are required to be free of pests. Pine bark and potting medium used in Florida's multibillion dollar ornamental and foliage industry are infested with insects that the European Community countries do not wish to import. Additionally, a previously $60 million export in wood chips to Scandinavian countries has declined to $3 million per year due to nematode infestation in southern pinewood chips. Wood chips and bark could be exposed to electrons under a 2.5 meter horn to control pests as they pass by conveyor belt into ships.

Other countries use irradiation to control diseases in beehives. X-rays have been used to decontaminate a demonstration hive in the Division of Plant Industry headquarters. Approval of beehives irradiation is currently delayed since minute amounts of honey may remain in treated hives and be consumed by bees and only bagged animal food has been approved. FDA seems to be looking more favorably upon irradiated food. Poultry has been approved and red meats are under study for approval of irradiation to reduce bacterial contamination. There is an urgent need to get more approvals for irradiation as a quarantine treatment for fruits, vegetables, and other agricultural commodities. Perhaps workshops such as this and future ones will help provide opportunities to get more approvals of irradiation as a quarantine treatment.

FIGURE 1. Longitudinal Section of Florida Agricultural Commodities Irradiator



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Questions, Answers, Comments and Discussion on Burrell J. Smittle's Presentation

Question: How many cartons do you have on your pallets?

Speaker: You normally have a stack of 63.

Question: When you said Florida ships out 23,000,000 boxes, what percentage of that 23,000,000 are fumigated?

Speaker: I don't know.

Question: I guess what I am trying to get into....suppose that you had to irradiate...irradiation became the only alternative and you had to irradiate at harvest time, say grapefruit? How many can one irradiator (handle)?

Speaker: In our facility, we do one at a time, and then we have to turn around and do the other side. Now, if we are talking about a facility like Vindicator, they can put 16 pallet loads around the cobalt source at one time; Vindicator may want to answer how many they can do/hour or per/day, or something of that nature. ... I don't want to put anyone on the spot, from Vindicator, but maybe I already have.

Vindicator: We can do about 70 truck loads a day, working at that level, 1000 boxes per truck load, nine per layer, and seven high.

Question: We are getting down to what we are looking at from the logistics of this operation, ...something, ...how many irradiators do we need?

Speaker: Maximum, as I recall, about 400 truck loads have been fumigated at Waneta in a week, is that right? So you see that if he can handle that many per day, he can take care of our needs.

Question: What is the weight of a box of grapefruit?

Speaker: A box of grapefruit weighs around 50 pounds, right? Or maybe forty.

Comment: Very good, I know that you have used irradiation for honeybees in Canada. We don't have the same situation in Canada with animal food being considered...being regulated as food.

Comment: We do have problems with irradiated animals and if the "anti-people" get a hold of it, there could be lots of problems.

Comment: So!! There are some people that are going to protest anytime, and regardless.

What we need to look at and one of the things this meeting is going to be very important for as Dr. Sharp mentioned about the sweet potato weevil; you can irradiate a lot of insects at a very low dosage. Every day now, using a little Cesium irradiator, we irradiate about a million carib flies every day with about five kilorads and we never get any adults emerge. This happens to be for rearing a parasite that we are using to supplement our fly free zone. In Florida we have a lot of integrated programs. We are in the process of changing over to our linear accelerator to irradiate these larvae. It now takes about five minutes to do 750 ml, that's about 30 some thousand per load and we do about 30 loads a day. When we get our facility on line in five minutes we can do 20 million; we can't quite rear that many per day, but we can rear that many in a week. We hope that some of you will visit the carib fly rearing facility which is right next to the irradiator, tomorrow afternoon. We have a big group here, and we may have to split you up, so one group visits the fly lab while another visits the irradiator.

ARS: Have you done anything on oak wilt disease, or something more dense than chips, maybe logs?

Response: No, but we have had some inquiries on that. George Deitz, have you done anything like this with cobalt in any of your facilities?

Response: Absolutely not. I had inquiries about what it takes to take whole logs and irradiate them for shipment to Japan.

Comment: We have a huge market for oak logs going to Europe, and because of oak wilt disease they have to be fumigated with methyl bromide, currently we don't know of any treatment that will work except for fumigation. Probably they would, some of them would be over two feet in diameter.

Question from (Mary Carter?): Why don't we just ship the lumber. That's ridiculous.

Comment: In blueberries, you mention doses up to 1.5 kG. ...does the Florida blueberry industry have a mold spoilage problem that would warrant over 1 kGy?

Speaker: I'd have to, ask Dr. Miller right here who has been working on that.

Comment: In general, not with Rabbit Eye cultivar here in Florida and the southeast. How much does a facility cost?

Speaker: To have a linear accelerator facility like this? Well, at our facility here, you are talking in the neighborhood of $6,000,000. Now, ... there are several APHIS people around here who may have other information. There are some companies now that are making small, truck mounted linear accelerators for treating smaller loads. They are looking for replacements for some of our cobalt and cesium irradiators that are used in their mass rearing facilities, like in Mexico and Guatemala etc. If you have a need for some of these things, there are a lot of companies around.

Talk to Dr. Marsh Cleland here who makes dynamitrons. He makes them for different kinds of uses. If you go into a tire manufacturing facility almost anywhere in the country, you are probably going to see some dynamitrons. They are used to change the copolymer structure of rubber, so that they don't have to heat it up much, and to produce a lot of plastics wire, insulation, shrink wrap plastic, etc.

George Deitz is right here in the back, with ISOMEDIX where they do millions and millions of boxes of medical products. And Bill Hargraves of Vindicator has done a lot of other types of produce, oranges and tomatoes, etc. So there's a fellow here from Titan has built some other facilities, so there are people here that can give you some other figures. But that's basically what we are talking about with our linear accelerator. If Bill wants to quote on that or any of these people from Canada, Joe, you can maybe give us an idea, you sell linear accelerators, since you have 2 different accelerators, you've got one out there at your place, and the other one. You recently sold two of them. I don't know what the cost is. I can't tell you about other irradiators, but a lot of the people in the room can.

DOSIMETRY TECHNIQUES REQUIRED TO ENSURE COMPLIANCE WITH QUARANTINE TREATMENT PROTOCOLS

by

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simetry Techniques Required to Ensure Compliance with Quarantine Treatment Protocols

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1. Introduction

There are several different treatments currently providing quarantine security for imported and exported fruits and vegetables to and from the Un:· ·l States. Each has its advantages and disadvantages, but a widely used treatment, fumigation wi ı methyl .:omide, is likely to be phased out in the near future due to its harmful effect on the Earth's ozone layer. The alternative treatments using hot air, hot water, other fumigants or refrigeration, while effective, frequently have deleterious effects on the product. Treatment using irradiation, on the other hand, can provide total quarantine security while sometimes increasing the shelf life of the product. As with other processes, however, the effectiveness of the irradiation process depends on the proper application of the treatment - in this case the radiation dose and its measurement.

Unlike the presently-used gas, heat, or cold treatments which kill all the transported larvae, pupae, or adult insects, the irradiation treatment instead sterilizes or prevents adult emergence. This difference is not important from the technical point of view since sterilization is all that is needed to assure quarantine security. This difference is important from an implementation point of view, however, because if a live larva, pupa or an adult insect is found in the product after irradiation, there is at present no easy physical test to determine if the insect is indeed sterile. Providing additional irradiation to prevent adult emergence is not absolutely necessary, and in some cases it is undesirable, but this would make it easier for inspectors to eliminate as a source of infestation a load of irradiated product if adult insects were found in the vicinity. Adding even more radiation to kill the insects outright is really not a viable option because at these relatively large doses, unacceptable changes to the fruit or vegetables would be expected.

At this point, it is time to generate a well-thought-out quality control program that includes rigorously tested standardized dosimetry procedures. The concept of using quality controls along with dosimetry as a method of releasing product is, of course, nothing new. The international medical industry has relied on this method for years to assure the complete safety of irradiated sterilized medical products and devices. Under the supervision of the US Food and Drug Administration (FDA), over 50 % of the United States medical disposables are now routinely sterilized using the irradiation process - in a fashion that is essentially identical to the way produce would be irradiated for quarantine security.

2. Absorbed Dose

The effect of radiation on an insect or on any food product depends on the absorbed dose, which is simply the amount of energy absorbed. The dose can be provided by x-rays, gamma rays, bremsstrahlung (radiation emitted when electrons are slowed down), or by electrons striking the product directly. In each case, the desired effect is caused by electrons - - either electrons coming directly from a machine, or by electrons released by the interactions of the gamma or bremsstrahlung radiation with individual atoms in the product. Gamma rays would normally come from ^{60}Co or ^{137}Cs radioactive pencils, whereas x-rays and bremsstrahlung radiation are generated by electron-beam machines where electrons strike a target instead of striking the food directly.

As shown in Figure 1, x-rays, gamma rays, and bremsstrahlung radiation can penetrate distances of a meter or more into the product, depending on the product density, whereas electrons, even with energies as high as 10 MeV, can penetrate only a few centimeters.

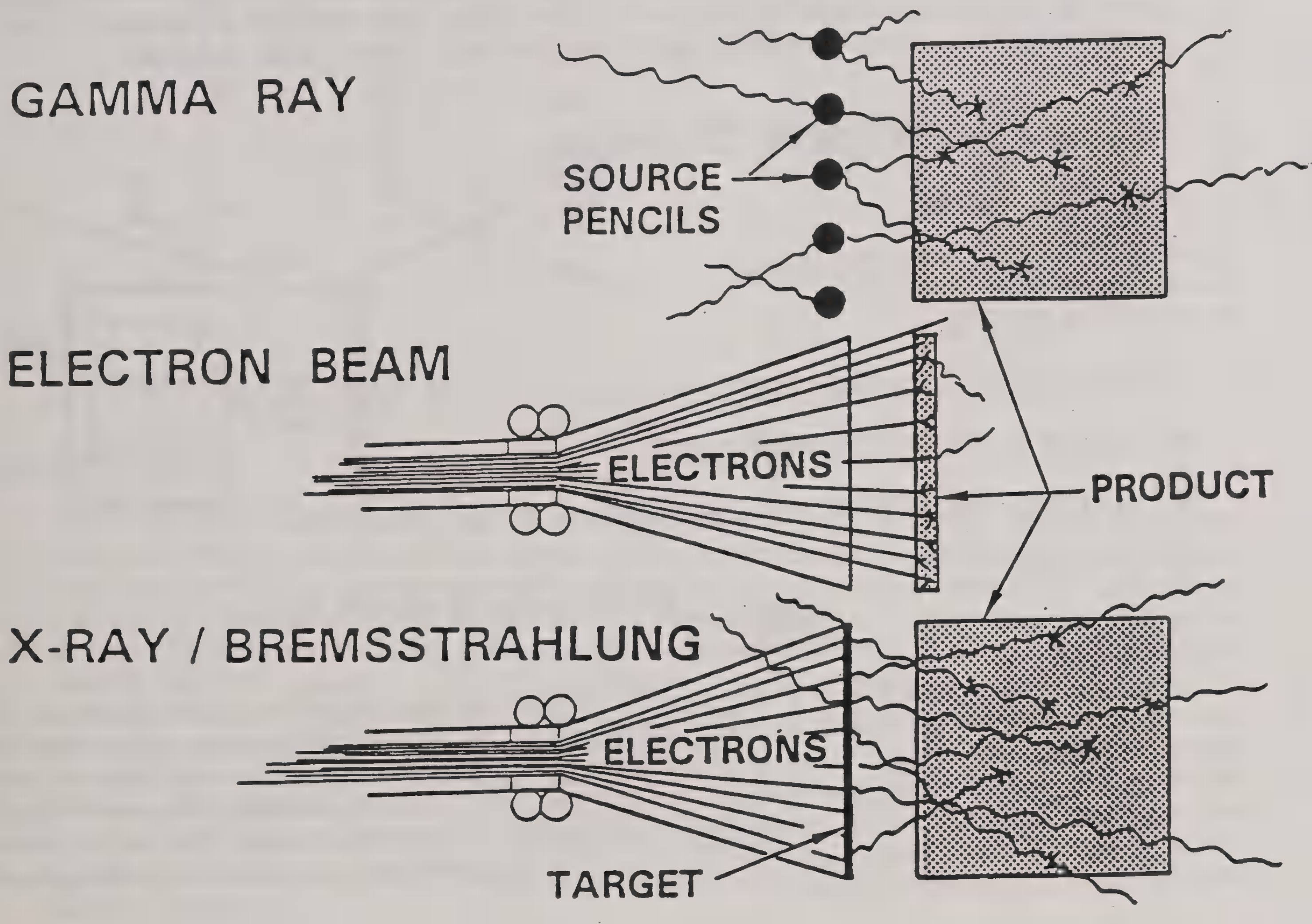

Figure 1. Some typical sources used for radiation processing

By using a heavy-element target, an electron-beam machine can generate x-rays and bremsstrahlung radiation which can penetrate the product in the same way as gamma rays. The important point, however, is that it makes no difference which type of source is used; it is the electrons (shown in Figure 1 as small stars) that create the effect.

3. Dose Distribution

Clearly, the ideal irradiation situation would be where all the product receives an identical dose. This would be the dose identified by research as being that necessary to accomplish the desired effect, which in the case of a quarantine treatment, would be the dose necessary to sterilize or prevent adult emergence of the insect. In practice, it is impractical to get a uniform dose for commercial quantities of product, and so efforts are made to minimize the range of dose experienced in each box or pallet-load of produce. Usually, the minimum dose is dictated by a government agency in the treatment protocol, and the maximum dose is set below the amount where undesirable radiation effects start to occur.

There are a number of parameters that affect the dose distribution within the product. Figure 2 shows a case where gamma pencils in a source plaque are irradiating a carrier loaded with boxes of product passing by. The dose absorbed at any point within one of the boxes will depend on the type of the source pencils (^{60}Co or ^{137}Cs), their strength, their positioning (geometry) within the plaque, the amount of time the carrier spends near the source, the distance (d), the density of the food product, and the loading pattern in the carrier. Clearly, this dose distribution will change if there is a change in any of these parameters.

- STRENGTH AND TYPE OF SOURCE
- DWELL TIME
- GEOMETRY OF SOURCE
- DISTANCE d
- THICKNESS OF CARRIER
- DENSITY OF FOOD PRODUCT
- LOADING PATTERN IN CARRIER

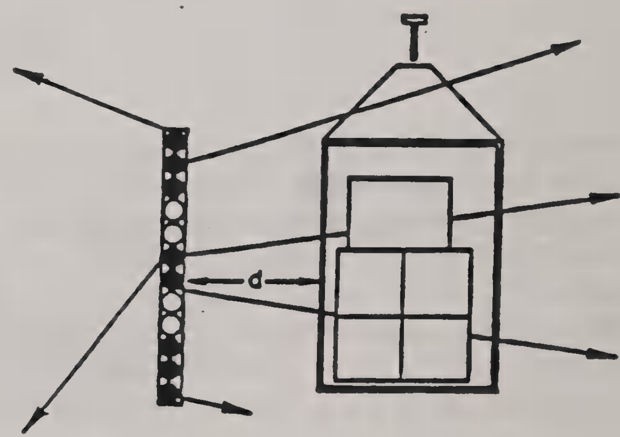

Figure 2. Parameters affecting absorbed dose

As can be seen from Figure 3, the absorbed dose will be higher at position A than at position B. To minimize the dose differences in the product (to bring the maximum to minimum dose ratio as close to unity as possible), the usual procedure is to irradiate the product from two sides as shown in Figure 4. There are many engineering methods to make the dose distribution more uniform, including 4-sided irradiation, using selective shielding, altering the distribution of the pencils in the plaque, or using other shaped plaques. In the case of electron-beam machines, the product usually makes multiple passes, each time presenting a different face toward the target.

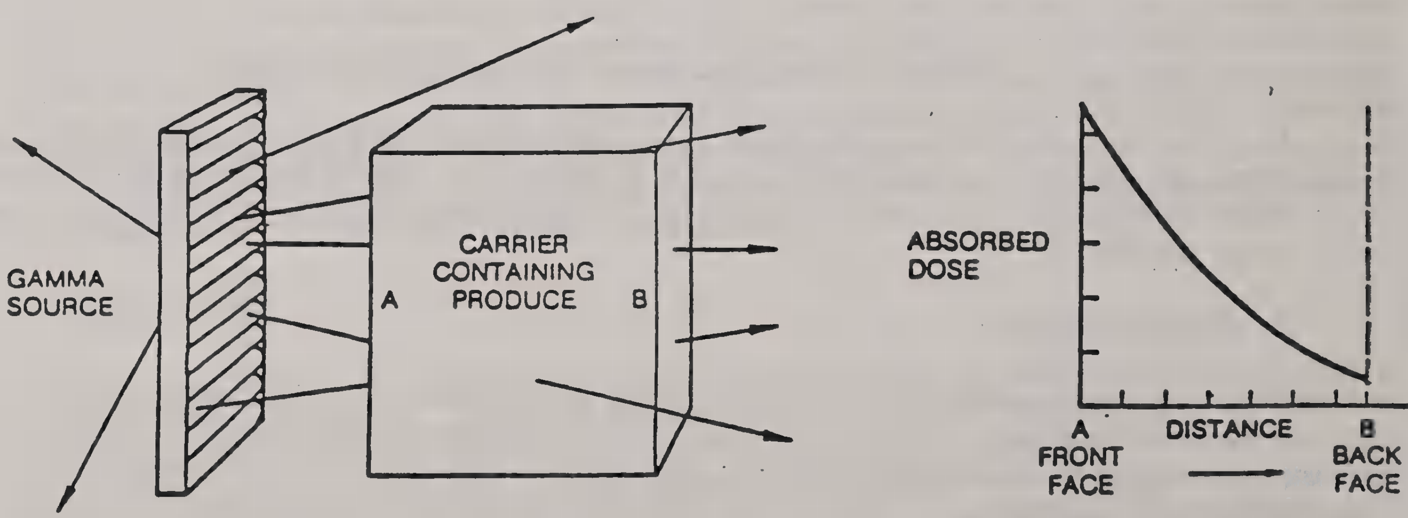

Figure 3. Absorbed dose as a function of penetration into product

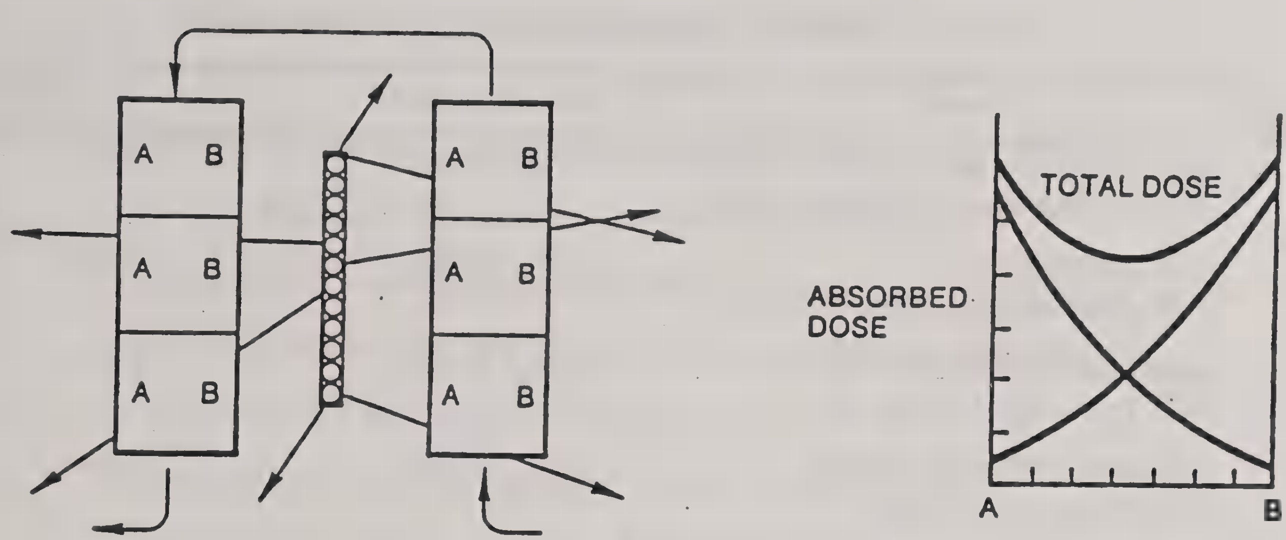

Figure 4. Typical absorbed dose distribution from a 2-sided gamma irradiation

4. Dosimeters

Dosimeters are used to measure absorbed dose and ensure that the food product receives the required treatment. Selection of an appropriate dosimetry system requires matching its performance with the specific application criteria. This selection process is described very well in Standard Guide E1261 "Selection and Application of Dosimetry Systems for Radiation Processing of Food", published by the American Society for Testing and Materials (ASTM). Briefly, the dosimeters must be accurate, be usable in the absorbed dose range of interest for quarantine treatments (sensitive down to ~40Gy), be rugged, be stable with time, have minimum sensitivity to environmental conditions (temperature, humidity, stray light etc.), and be traceable to national standards. ASTM procedures to calibrate a dosimetry system so that it is traceable to national or international standards have been written and are now undergoing a ballot process. Radiation-Sensitive Indicators (often known as Go/No-Go labels), on the other hand, can only indicate that some irradiation has occurred, and because they cannot be calibrated, they cannot be used to assure a minimum dose has been achieved. The limitations of these labels are described in ASTM Standard Guide E1539 "Use of Radiation-Sensitive Indicators."

A partial list of dosimeters now available for use in quarantine irradiation applications, their useful dose ranges, and the ASTM standards that specify how they must be used are given in Table 1.

5. Measuring Dose Distribution

The precise procedures for determining the absorbed dose in food are documented in two ASTM Standard Practices: E1204 "Dosimetry in Gamma Irradiation Facilities for Food Processing" (revised in 1993) and E1431 "Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing" (published in 1991). They outline the exact procedures to be followed in irradiator characterization, process qualification, and routine processing of food to ensure that all the product has been treated within a predetermined range of absorbed dose. Briefly, the process involves conducting an exhaustive dose mapping throughout each product loading configuration using many replicate dosimeters to determine the exact locations of minimum and maximum dose. This dose mapping must be performed for all product configurations prior to routine production operations.

Table 1. Dosimeters for Quarantine Applications

Name	Useful Dose Range	ASTM Standard
OPTICHROMIC DETECTORS Far West Technology, Santa Barbara, CA	10Gy - 20,000Gy	E1310
GAFCHROMIC FILM GAF Chemicals Corporation, Wayne, NJ	20Gy - 3000Gy	E1275
GAMMACHROME DETECTORS AEA Technology, Harwell, UK	100Gy - 3000Gy	E1276
ALANINE-EPR DOSIMETERS GSF, Neuherberg, Germany	1Gy - 1x10^{5}Gy	E1607
ETHANOL-CHLOROBENZENE Institute of Isotopes, Budapest, Hungary	10Gy - 2x10^{6}Gy	E1538

6. Routine Dosimetry

Once the dose mapping is complete for a given product loading configuration, and for a given set of operating parameters, dosimeters are placed periodically only at the maximum and minimum locations during routine operations. If the maximum or minimum locations are not readily accessible, however, dosimeters may be placed at reference dose positions where a relationship can be established between the absorbed doses at the reference position and the maximum or minimum absorbed dose positions.

The placement of a dosimeter on each box of produce, on the other hand, is unnecessary and indeed *misleading*. This is because it would be highly coincidental if these dosimeters happened to be situated at either the maximum or at the minimum dose locations; therefore, the resulting dose measurements would give intermediate readings between the true maximum and minimum doses. The resulting massive amounts of data would have little value since they would provide neither of the two desired numbers, and would, in fact, show an artificially narrow dose distribution.

The concept of "overall average dose" is also of little or no interest in radiation quarantine treatment. Again, the only doses of interest are the minimum dose and, to a lesser extent, the maximum dose.

7. Dosimetry Standards

For irradiation treatments to be reproducible in the laboratory and then in the commercial environment, and for products to have certified absorbed doses, standardized dosimetry techniques are needed. This need is being satisfied by standards being developed by ASTM Subcommittee E10.01, which consists of a group of ~170 experts from 46 countries. Table 2 lists 24 ASTM dosimetry standards for radiation processing, 15 of which have been published in Volume 12.02 of the 69-volume Annual Book of ASTM Standards. Most of the others are in the process of being balloted, a procedure that requires unanimous technical consensus of all the interested parties. Twelve of the standards in Table 2 are practices on how to use specific dosimetry systems for radiation processing. Seven of the standards are practices on how to characterize and use gamma, x-ray, and electron beam irradiation facilities. The other standards give procedures on how to calibrate dosimeters (making them traceable to national or international standards); how to treat dose uncertainties; how to perform dose mappings; and how to run a standards calibration laboratory. Together, when completed, this group of standards will cover all aspects of dosimetry for radiation processing. Plans are also to publish the complete set as a separate ASTM handbook.

Table 2. ASTM Dosimetry Standards for Radiation Processing.

Description	Title
E1026	Practice for Using the Fricke Reference Standard Dosimetry System
E1204	Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing
E1205	Practice for Use of a Ceric-Cerous Sulfate Dosimetry System
E1261	Guide for Selection and Application of Dosimetry Systems for Radiation Processing of Food
E1275	Practice for Use of a Radiochromic Film Dosimetry System
E1276	Practice for Use of a Polymethylmethacrylate (PMMA) Dosimetry System
E1310	Practice for Use of a Radiochromic Optical Waveguide Dosimetry System
E1400	Practice for the Characterization and Performance of a High Dose Gamma Radiation Dosimetry Calibration Laboratory
E1401	Practice for Use of a Dichromate Dosimetry System
E1431	Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing
E1538	Practice for Use of an Ethanol-Chlorobenzene Dosimetry System
E1539	Guide for Use of Radiation-Sensitive Indicators
E1540	Practice for Use of a Radiochromic Liquid Solution Dosimetry System
E1607	Practice for Use of the Alanine-EPR Dosimetry System
E1608	Practice for Dosimetry in an X-Ray (Bremsstrahlung) Facility for Radiation Processing
E10.01-G	Guide for Estimating Uncertainties in Dosimetry for Radiation Processing (in ballot)
E10.01-H	Practice for Use of Calorimetric Dosimetry Systems for Electron Beam Dose Measurements and Dosimeter Calibrations (in ballot)
E10.01-I	Practice for Dosimetry in a Gamma Irradiation Facility for Radiation Processing (in ballot)
E10.01-L	Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 80 and 300 kev (draft)
E10.01-R	Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing (in ballot)
E10.01-S	Guide for Dose Mapping Product in Radiation Processing Facilities (outline)
E10.01-T	Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies between 300 kev and 25 MeV (in ballot)
E10.01-W	Practice for Use of a Cellulose Acetate Dosimetry System (in ballot)
E10.01-X	Practice for Dosimetry in a Self-contained (Blood) Irradiator (outline)

The unanimity requirement of the ASTM balloting process and the wide range of experience and geographic locations of the subcommittee members give the standards particular credibility for specifying how research or production operations should be done properly.

8. Food Processing and Packaging Standards

Another ASTM group, Subcommittee F10.10, is generating radiation-related standards on food processing and packaging. Of interest to the quarantine community is their recently-published Standard F1355 "Guide for the Irradiation of Fresh Fruits for Insect Disinfestation as a Quarantine Treatment." This standard was based on a Code of Good Irradiation Practice developed by the International Consultative Group on Food Irradiation (ICGFI).

9. Dose Assurance

ASTM standards E1204 and E1431 for conducting dosimetry in irradiation facilities for food processing give very specific procedures for performing dosimetry during routine production processing of food. They also cover certification, documentation, facility logs, and retention of records. These two, and other ASTM standards are specifically referenced in the US Department of Agriculture's rule 9CFR Part 381 "Irradiation of Poultry Products."

Similar irradiation procedures have been used widely and routinely in the US, Canada, and Europe for a number of years by the medical devices industry for sterility assurance. Procedures and standards generated by the Association for the Advancement of Medical Instrumentation (AAMI), which are now being balloted as ISO standards, are relied upon by the US Food and Drug Administration and similar national regulatory bodies in other countries. For example, Document AAMI/ISO 11137 "Sterilization of Health Care Products - Requirements for Validation and Routine Control - Radiation Sterilization" covers validation, process control, and routine monitoring in gamma, electron beam, x-ray, and bremsstrahlung radiation facilities for processing health care products. This ISO standard, which refers to the ASTM standards for specific dosimetry systems, describes the requirements for assuring that the activities associated with the process of radiation sterilization are performed properly. These activities comprise documented work programs designed to demonstrate that the radiation process, operating within specified limits, will consistently yield products treated with doses that fall between predetermined limits.

10. Overall Quarantine Security of the Process

As with the sterilization of medical instrumentation, the process of quarantine irradiation has to rely on a validated and rigorously controlled protocol. For the overall process to be acceptable, however, attention has to be given to the prior status of the product being irradiated, including its packaging and handling. Clearly, a shipment of fruit with numerous live larvae will be unacceptable to the customer whether or not the larvae are sterile!

As a result, as with the hot water, hot gas, fumigation, or cold treatments, it is imperative that the fruit and vegetables being treated are of high quality and are essentially insect free. Again, as with those other treatments, fruit and vegetables that are undamaged will hold up to irradiation much better than mishandled product. The irradiation treatment should *not* be used to "clean up" the product, but should be used to provide the additional overall security which is the basis for quarantine.

11. Conclusions

It is clear from the above discussions that standardized dosimetry procedures for quarantine irradiation are in place and have been used routinely for years for other applications in the US and abroad. In the case of medical devices, the assurance of sterilization has been provided to the satisfaction of regulatory agencies simply by rigorous quality assurance and quality control programs along with these standardized dosimetry techniques. The use of similar procedures for the quarantine release of food products, when there still is no readily available test to determine if the product has undergone the treatment, should be equally acceptable to regulatory agencies, worldwide.

In summary, the technology to release product on the basis of dosimetry, when combined with a proper QA/QC program, is proven, reliable, and routine.

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Questions, Answers, Comments, and Discussions on Dr. Harry Farrar's Presentation

Question: Could I ask for a clarification of the relationship between, the ASTM standards relating to packaging that are being developed, and how they relate to the USFDA specifications or requirements regarding packaging for irradiated foods.

Speaker: The purpose of the ASTM standard is not to replace or supplement the FDA regulations on packaging materials for food to be irradiated. It's basically going to deal with issues. First of all, the standard is a guide to advise people that there are indeed regulations, because many people are not aware of the fact that regulations exist that they have to meet. Secondly, the guide will talk about the effects of irradiation on packaging material and perhaps provide some rationale for why the FDA regulates. The guide will also tell people about particular packaging configurations that are needed for certain products, depending upon density, and we hope it will also go into the issue of dealing with oxygen permeability, the reason why it's important and, perhaps how to measure it.

Question: Will the ASTM standard guide on packaging materials for irradiation actually identify the different types of film types which are suitable?

Speaker: No, it's not going to be a catalog.

Comment: About a year and a half ago I phoned different companies that manufacture radiation sensitive indicators to see if they had an indicator that was developed and available that would operate at disinfestation dose levels. I didn't find anybody that would admit to having one that was both developed and available and that would operate at disinfestation dose levels, not to mention all the environmental sensitivity problems. So, I think that people shouldn't put any reliance on these indicators being available.

Speaker: Radiation sensitive indicators can only show whether or not something has been irradiated. They don't say anything about the amount of the dose, they just show that it has just been irradiated.

Comment: In some cases, they may not even be able to do that...

Speaker: You're right.

Comment: Well, Harry, would you please mention what dosimeters are available, and their accuracy at this relatively low dose level. Can you give the range and degree of accuracy?

Speaker: We are talking about a ten percent sort of accuracy. Three or four percent of that is due to the uncertainties in the calibration process, but the national standards are only known to 3 or 4%. The

Speaker: We are talking about a ten percent sort of accuracy. Three or four percent of that is due to the uncertainties in the calibration process, but the national standards are only known to 3 or 4%. The final uncertainty will depend on the individual system chosen, but the actual uncertainty you achieve depends on how many dosimeters you put at any individual location. For example, there is commercially available radiochromic, liquid dye solution sealed in the middle of a miniture light pipe. After irradiation, an instrument determines the light absorption of the solution to get the dose measurement.

Comment: For quarantine you were talking about 100 Gy. Are there other dosimetry systems that are sensitive at this low dose level?

Speaker: Yes, several are listed in Table 1 of my paper.

Comment: I think that there are some people who are unaware that there are dosimeters available for this sort of thing. Some dosimeters can be rather inaccurate, so you have to be very careful about the dosimetry system you choose. ASTM has developed a guideline on choosing the most appropriate dosimetry system for a given application.

Comment: One of the commercial plastic dosimetry films goes down to the dose range we are talking about.

Speaker: We have an ASTM standard on radiochromic films that applies to the GAF-Chromic dosimeters.

Comment: Right now, some people are using them.

Question: What is the reliability of a radiochromic film as a dosimeter versus its use as a radiation sensitive indicator? Has there been some work done to use radiochromic films as Go/No Go indicators? What degree can you rely upon them?

Speaker: There are a lot of tests that you have to do to check for temperature or ultraviolet sensitivities, etc.. You have to be very careful when you calibrate dosimeters at one dose rate. For example, at a low dose rate, and then you use them in a production irradiator where the dose rate is 100 times higher. For some dosimeter types, there can be a difference. On the other hand there are some very good dosimeters that have negligible dose rate effects. The best way of calibrating dosimeters is to obtain some good quality "transfer standard" dosimeters, for example, from NIST or NPL in Great Britain, and put them together with your routine dosimeters, which you don't know anything about. You then irradiate them together in your own facility. By calibrating them this way, you put them through your system, which has a variety of dose rates and temperature ranges. After the irradiation in your own facility, you send the transfer standard dosimeters back to NIST or NPL, they will tell you what dose you actually got. You then use this dose to calibrate your own routine dosimeters.

Comment: I want to say that we have made dosimeters that are responsive down to 100 Gy.

Question: I thought there was a radiation-sensitive indicator that is responsive down to about 100 Gy?

Speaker: In general, the dosimetry community is not very interested in the use of radiation-sensitive indicators. We have here Marshall Cleland who is chairman of the group that wrote on ASTM standard on how to use and how not to use them. I think it is important to discuss real dosimeters which can be used to measured dose accurately.

USE OF IRRADIATION AS A QUARANTINE TREATMENT OF FRUITS AND VEGETABLES: IMPLICATIONS TO INTERNATIONAL TRADE

by

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USE OF IRRADIATION AS A QUARANTINE TREATMENT OF FRUITS AND VEGETABLES - IMPLICATIONS TO INTERNATIONAL TRADE

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INTRODUCTION

A major milestone in food irradiation occurred in 1980 when the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI) concluded that "Irradiation of any food commodity up to an overall average dose of 10 kGy causes no toxicological hazard; hence, toxicological testing of food so treated is no longer required (WHO, 1981). The JECFI also stated that irradiation of food up to a dose of 10 kGy introduces no special microbiological or nutritional problems. The conclusions and recommendations of the JECFI were elaborated into an international standard under the procedure of the Codex Alimentarius Commission (CAC) of the Joint FAO/WHO Food Standard Programme. The CAC has as its primary objectives in protecting consumer health and ensuring fair practices in the food trade. The procedure of the CAC requires several rounds of governments' comments. In 1983, the CAC, then represented by some 130 governments, decided to adopt a Codex General Standard for Irradiated Foods and a Recommended International Code of Practice for Operation of Radiation Facilities used for Treatment of Food. The Codex Standard and its associated Code of Practice provide important principles for proper irradiation of food (up to an overall average dose of 10 kGy) and essential control procedures. The Codex Standard was recommended by the CAC to all its members for acceptance in 1984.

The Codex Standard provided an important incentive for national authorities to introduce regulations on food irradiation. In fact, starting from the early 1980's several advanced countries including the USA, U.K., France, Canada, Denmark, the Netherlands, etc. and many developing countries including Bangladesh, Chile, China, India, Brazil, Mexico, Thailand, Republic of Korea, etc. had introduced national regulations on food irradiation following the principles of the Codex Standard. Currently, 37 countries have approved collectively more than 100 irradiated food items or groups of food for consumption, either on an unconditional or restricted basis.

To provide government and the food industry with appropriate information and guidance on control procedures for food irradiation and irradiated foods, especially those destined for international trade, the International Consultative Group on Food Irradiation (ICGFI) has developed a number of technical documents to complement the Codex Standard, since its establishment in 1984. ICGFI is sponsored by FAO, IAEA and WHO with the primary function to the three Organizations and their Member States and to evaluate global development in the field of food irradiation. Currently, ICGFI has 39 member governments, the majority of which are from developing countries, which provide in-cash or in-kind support towards ICGFI activities.

TRENDS IN COMMERCIAL USE OF IRRADIATED FOOD

Approvals of irradiated food are made mainly from the safety and regulatory points of view and do not necessarily imply that commercial application of such food would be automatically followed. Commercial applications of food irradiation, while still limited in quantities, are presently carried out in 26 countries as per Table 1. The most common irradiated food products for commercial use are spices and vegetable seasonings, some 20,000 tons are estimated to have been irradiated in 1992 (Loaharanu, 1993). The ban on the use of ethylene oxide as a food fumigant by the EC in 1991, which is being enforced, is likely to increase the quantity of spices and vegetable seasonings processed by irradiation in the near future. The quantities of irradiated food produced for commercial purposes in different countries vary significantly from several tons to hundreds of thousand of tons per annum. It is estimated that the total quantity of irradiated food produced by various countries in the past 20 years is approximately 5,000,000 tons, the majority of which has been produced in the Ukraine with an annual turn over of some 400,000 tons of grain in the past 10 years.

It is significant to note that the majority of increase in the production of irradiated food occurred in the past five years, partly because of the increasing restriction on the use of food fumigants and partly because of the better understanding of the food industry and the public on the safety and benefits of irradiated food. A major milestone on commercial application of food irradiation occurred in early 1992 when the first commercial food irradiator in the USA went into operation near Tampa, Florida. Irradiated strawberries, citrus, mushrooms, poultry, onions, etc. have been successfully sold at retail level in Florida and Illinois since then (Marcotte, 1992; Pszczola, 1992; Pszczola, 1993). The operation of the irradiator and the sale of irradiated food in the USA have attracted wide public attention and served the purpose in informing consumers of safety and benefit of irradiated products.

Commercial application of irradiation to ensure hygienic quality of food, especially those of animal origin, has already started in Belgium, Chile, China, France, the Netherlands, South Africa, Thailand and USA, is likely to increase once the food control authorities, food industry and consumers have a better appreciation of the risk involved in non-irradiated products and the role of irradiation in this aspect. The use of irradiation to "pasteurize" solid food such as meat, poultry, seafood, spices, etc. could in the future be comparable to the use of pasteurization of liquid food such as milk, fruit juices, etc. The use of thermal pasteurization of such liquid food, while effective and widely accepted, is not suitable for solid food and dry food ingredients.

INTERNATIONAL DEVELOPMENTS ON IRRADIATION AS A QUARANTINE TREATMENT

The effectiveness of irradiation as a quarantine treatment of fruits and vegetables was first evaluated by an international group of experts convened by FAO and IAEA in 1970 (IAEA, 1971). Although it was recognized at the time that irradiation is an effective quarantine treatment of such commodities, there was no economic incentive in using the technology in view of the wide use of fumigants especially ethylene dibromide (EDB) to overcome quarantine restriction. Following the ban on EDB in the USA in 1984 which caused detrimental effect to trade in fresh fruits and vegetables, irradiation was considered as an alternative to EDB. In 1986, the ICGFI convened a Task Force on Irradiation as a Quarantine Treatment to evaluate available data on radiation sensitivity of various fruit fly species and other quarantine arthropod pests and phytotoxicity of commodities treated for this purpose. On the basis of these data, the Task Force recommended a minimum effective dose of 0.15 kGy as a quarantine treatment of fresh fruits and vegetables against fruit fly of Tephritidae family and 0.30 kGy against other insect pests including mango seed weevil (ICGFI, 1986).

Additional data on radiation sensitivity of several more fruit fly species, other insects and mites have been generated under the FAO/IAEA Co-ordinated Research Programme on the Use of Irradiation as Quarantine Treatment of Food and Agricultural Commodities, between 1986 and 1990. These data together with those on the use of conventional quarantine treatments were evaluated by the second Task Force on Irradiation as a Quarantine Treatment of Fresh Fruits and Vegetables, in 1991. This Task Force confirmed the findings of the earlier task force as stated above. Unlike other quarantine treatments which are either commodity or pest specific, irradiation is an effective and broad quarantine treatment against various species of fruit fly and other insect pests without adversely affecting the quality of most host commodities.

The effectiveness of irradiation as a broad quarantine treatment of fresh fruits and vegetables was recognized by the North American Plant Protection Organization (NAPPO) in 1989. NAPPO is represented by national plant protection authorities in Canada, Mexico, and USA. In addition to NAPPO, other regional plant protection organizations including European Plant Protection Organization (EPPO), Asia and Pacific Plant Protection Commission, and Organism International Regional de Sanidad Agropecuaria (OIRSA), have endorsed the use of irradiation as a quarantine treatment of fresh horticultural products at the Technical Consultative of Regional Plant Protection Organizations, held in San Salvador in 1992 (FAO, 1992)

DEVELOPMENTS OF QUARANTINE TREATMENTS IN EUROPE

Currently, EPPO is evaluating quarantine procedures and measures as a follow-up of European Single Law Act which is in force since January 1993. The act allows free circulation of any goods including food and agricultural products, once enter any member country of the European Union (EU), throughout the 12 member countries of the Union without restrictions. A number of food and agricultural commodities imported from other regions may be host to insect pests which could become established in sub-tropical areas around the Mediterranean. It is well known that countries such as Spain and Israel are growing increasingly large commercial quantities of fruits such as mangoes, papaya, pineapple, banana, cherimoya which may become host to a number of exotic fruit fly species. To protect agriculture of some members of the EPPO against such fruit fly species, EPPO Workshop on Pest-Risk Analysis of Non-European Fruit Flies was convened in Paris last September and agreed to make provisional classification of the fruit flies as follows:

1. Species presenting a definite risk to the EPPO region:

Bactrocera cucurbitae, B. dorsalis, B. mimac, B. tsuneonis, Ceratits rosa, Dacus ciliarus, Rhagoletis pomonella, R. mendax, R. cingulata, R. indifferans, and R. fausta.

2. Species requiring further study of the risk of establishment and economic importance to the region:

Anastrepha fraterculus, A. luden, a. obligua, A. suspensa, Bactrocera cucumis and B. tryoni.

3. Species presenting a minor risk to the region:

Bactrocera zonata, Ceratiris cosyra, C. quinaria, Rhagoletis completa, R. ribicola, R. suavis, Euphranta japonica, etc.

Among the consignments which may contain fruit fly species presenting a definite risk to EPPO region, the following quarantine requirements and measures will soon be imposed;

1. The consignment must have been treated according to EPPO Quarantine Procedure No...........

2. The consignment must come from a place of production inspected, with its immediate vicinity, monthly during the 3 months before harvest and found free from such species.

3. The consignment must come from an area where such species do not occur.

Thus, quarantine barriers will soon be imposed by European countries especially those of the EU to protect health of local agriculture.

Irradiation as a quarantine treatment of fresh horticultural products is being considered by EPPO Panel on Quarantine Treatments along with other treatments, as a measure to overcome such barriers.

INTERNATIONAL TRADE IN IRRADIATED FOOD - IMPLICATION TO GATT

The recent successful conclusion of the General Agreement on Tariffs and Trade (GATT) Multilateral Trade Negotiation, Uruguay Round, in December 1993 is likely to increase global trade in irradiated food. The Uruguay Round of GATT Negotiation resulted in a number of agreements governing global trade in many commodities including food and agricultural products. Future trade in food and agricultural products will be determined by the Agreement on Sanitary and Phytosanitary Measures under GATT which aims at removing unjustified non-tariff barriers to trade. The Agreement will assist governments which are signatories to GATT to harmonize national sanitary and phytosanitary regulations and measures on the basis of appropriate standards established by:

a. Codex Alimentarius Commission-CAC (Food safety and health)

b. International Plant Protection Convention-IPPC (Plant health)

c. International Office of Epizooties-OIE (Animal health)

Under the Agreement, measures taken to protect human, animal and plant life and health are to be consistent with sound scientific evidence and use of suitable principles of equivalency. Such principles will not allow discrimination between imported and domestically produced goods. A Committee on Sanitary and Phytosanitary Measures is about to be established by GATT to oversee the implementation of the Agreement and to monitor the use of international standards issued by the CAC, IPPC, and OIE.

As the safety of irradiated food is already established by the Codex General Standards for Irradiated Foods, no government which is a signatory of GATT can deny entry of such food on the ground of irradiation treatment unless the government can prove that such food are not safe to human, animal or plant life and health. With regard to the use of irradiation as a quarantine treatment of fresh fruits and vegetables, the recommendations of the ICGFI on the minimum doses of 0.15 kGy against fruit fly of Tephritidae family and 0.3 kGy against other quarantine arthropod pests which have been endorsed by regional plant protection organizations, is likely to be incorporated into a standard of the IPPC in the near future. When such a standard is established, irradiation can be used to overcome quarantine barriers in trade in fresh fruits and vegetables on a global basis.

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Table 2. Countries with Irradiated Facilities
Available for Food Processing (January 1994)

Underlined facilities are under construction or planned
Underlined countries are irradiating food for commercial use

Country	Location (starting date for food irradiation	Produce
Algeria	Mascara	Potatoes
Argentina	Buenos Aires (1986)	Spices, spinach, cocoa powder
Bangladesh	Chittagong (1993)	Potatoes, onions, dried food
Belgium	Fleurus (1981)	Spices, dehydrated vegetables, deep frozen food
Brazil	Sao Paulo (1985)	Spices, dehydrated vegetables
Canada	Laval (1989)	Spices
Chile	Santiago (1983)	Spices, dehydrated vegetables, onions, potatoes, poultry meat
China	Chengdu (1978)	Spices and vegetable seasonings; Chinese sausage, garlic
	Shanghai (1986)	Apple, potatoes, onions, garlic, dehydrated vegetables
	Zhengzhou (1986)	Garlic, seasonings, sauces
	Nanjing (1987)	[illegible]oes
	Jinan (1987)	[illegible]cified
	Lanzhou (1988)	[illegible]cified
	Beijing (1988)	Not specified
	Tienjin (1988)	Not specified
	Daqing (1988)	Not specified
	Jianou (1991)	Not specified
Czech Republic	Prague (1993)	Spices, dry food ingredients
Cote d'Ivoire	Adidjan	Yams, cocoa, beans
Croatia	Zagreb (1985)	Spices, rice, food ingredients
Cuba	Havana (1987)	Potatoes, onions, beans
Denmark	Riso (1986)	Spices
Finland	Homantsi (1986)	Spices

Country	Location (starting date for food irradiation)	Produce
France	Lyons (1982) Paris (1986) Nice (1986) Vannes (1989) Marseille (1989) Pouzauges (1991) Osmanville Sable-Sur-Sarthe (1992)	Spices Spices, vegetable seasonings Spices Poultry (frozen deboned chicken) Spices, vegetable seasonings, dried fruit, frozen frog legs, shrimp Not specified Not specified Camembert
Hungary	Budapest	Spices, onions, wine cork, enzyme
India	Bombay Nasik	Spices Onions
Indonesia	Pasr Jumat (1988) Cibitung (1992)	Spices
Iran	Tehran (1991)	Spices
Isreal	Yavne (1986)	Spices, condiments, dry ingredients
Japan	Hokkaido (1973)	Potatoes
Korea, Rep.	Seoul (1986)	Garlic powder, spices and condiments
Mexico	Mexico City (1988)	Spices and dry food ingredients
Netherlands	Ede (1981)	Spices, frozen products, poultry, dehydrated vegetables, rice, egg powder, packaging material
Norway	Kjeller (1982)	Spices
Philippines	Quezon City (1989)	Not specified
Poland	Warsaw (1984) Wlochy (1991) Lodz (1984)	
South Africa	Pretoria (1986) Pretoria (1971) Pretoria (1980) Tzaneen (1981) Kempton Park (1981) Mulnerton (1986)	Potatoes, onions Fruit Spices, meat, fish, chicken, fruits, spices Onions, potatoes, processed products Fruits, spices, potatoes Fruits, spices
Thailand	Bangkok (1971) Patumthani (1989)	Onions Fermented port sausage, enzymes, spices
Ukraine	Odessa (1983)	Grain

Country	Location (starting date for food irradiation	Product
United Kingdom	Swindon (1991)	Spices
USA	Rockaway, NJ (1984) Whippany, NJ (1984) Irvine, CA (1984) Gainesville, FL (1993) Ames, IA (1993) Mulberry, FL (1992)	Spices Spices Spices Not specified Not specified Fruit, vegetables, poultry
Vietnam	Hanoi (1991)	Onions, potatoes, seafood, spices, rice
Yugoslavia	Belgrade (1986)	Spices

CURRENT INTEREST IN AND PROSPECT FOR ADOPTING IRRADIATION AS A QUARANTINE TREATMENT PROCEDURE FOR HAWAII

by

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Current Interest in and Prospect for Adopting Irradiation as a Quarantine Treatment Procedure in Hawaii

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Abstract

The need for an efficacious quarantine treatment of papayas and other tropical fruits in Hawaii for the export markets exists. Thermal treatment methods as currently used are not always satisfactory. Irradiation as an efficacious quarantine treatment method has been tested, proven and recognized. In addition to controlling fruit flies, irradiation could also control other pests that infest ornamentals and herbs. Consensus from recent meetings of state agency and industry representatives indicates a strong interest in pursuing radiation technology for the state of Hawaii. A pilot irradiator is considered very useful for Hawaii and USDA to jointly conduct research and development in using this technology as a quarantine treatment for selected commodities.

The Need for an Efficacious Quarantine Treatment Technology for Hawaii

Fruit fly infestation of fruits and vegetables is a serious economic problem in Hawaii. Tropical fruits such as pineapples, papayas, and mangoes grown in Hawaii represent three different quarantine restrictions: pineapples of the Smooth cayenne variety are not required to be treated for export; papaya is a host for several species of fruit flies and must be treated before export; mango is not exportable because it is a host for fruit flies and mango seed weevils. Chemical fumigation and thermal treatment are not effective in controlling the seed weevils. Because of this, very limited quantity of mangoes are grown in Hawaii. And it will remain so until an effective and efficient quarantine treatment method is available.

Ethylene dibromide (EDB) was used as a USDA-approved fumigant for Hawaii grown papayas for the export markets from 1953 to 1984. When an effective fumigant is banned, it creates the problem of finding an alternative or substitute that can do the same job or better. In the year before EDB was banned by EPA in the United States, the tropical fruit industry in Hawaii was rushed into finding alternative quarantine treatment for papayas and other fruits. Researchers at USDA-ARS in Hawaii conducted experiments to develop the double-dip hot water treatment to replace EDB fumigation. Later, an improved vapor heat treatment, and a high temperature forced air ('dry heat') method were also developed and used on papayas [1]. The experiences in the past nine years in using these thermal treatment methods on papayas have shown that some of the following problems occur some of the times: less than ideal fruit quality, costly harvesting and inspection schedules, discovery of insects in treated fruits at destination ports, and loss of sales due to consumer dissatisfaction with thermally treated papayas [2, 3]. Part of the reasons for the lack of 100% efficacy of the thermal methods is due to the use of empirical approach in arriving at the treatment protocols. Chan's recent suggestion to use nonempirical approaches in arriving at a treatment based on scientific thermal process calculations is highly desirable [4].

Other plant materials such as ornamentals and herbs grown in Hawaii are also prone to pest infestation. These include cut plowers, orchids, foliage, some other nursery products, sweet basil, Asian basil, parsley, Chinese parsley, and other herbs. Most of these plants are infested with aphids, carmine spiders, mites, and thrips. Various disinfestation methods experimented such as chemical/pesticide dipping and some forms of thermal treatments have been used or experimented but they are either tedious or not satisfactory because of the injuries that could occur especially from the heat treatments. Yet, for Hawaii, these materials represent a sizable income for the farmers. According to 1992 statistics, wholesale farm values of all the ornamentals was $69.8 million, of herbs, $2.5 million, and of papayas (for export markets), $9.37 million [5]. It is obvious that an efficacious and flexible quarantine treatment for Hawaii is much needed.

Gamma-radiation -- an Efficacious Quarantine Treatment Technology

The technical feasibility and effectiveness of disinfesting various tropical fruits and vegetables by gamma-radiation have been demonstrated by studies conducted around the world in the past three decades. Balock and his coworkers [6,7] at the USDA laboratories in Honolulu reported in the mid-1960s their findings on the effects of gamma-radiation on various stages of three species of fruit flies, and on the effectiveness of using gamma-radiation as a quarantine treatment of fruits. Burditt wrote an excellent review in 1982 on irradiation as a quarantine treatment of fruit [8].

Irradiation studies of various tropical fruits by researchers at the University of Hawaii at Manoa from the mid-1960s to the early 1970s confirmed the efficacy of using irradiation for disinfestation and shelf-life extension of papayas and other tropical fruits in the dose range of 0.26 kGy to 0.75 kGy. This translates to mean that the disinfestation dose is suitable as a quarantine treatment [9]. USDA-APHIS in 1989 approved a minimum dose of 0.15 kGy as a quarantine treatment of Hawaii-grown papayas.

An international conference on Radiation Disinfestation of Food and Agricultural Products was held in Honolulu in November, 1983 with the objective of bringing state-of-the-art information to the food industry on the use of irradiation as a quarantine treatment [10]. Participants of the conference also had the opportunity to exchange views and opinions on issues of irradiation as a quarantine treatment that were as yet unresolved such as pinpointing the life stage of a fruit fly at which it is the most resistant to radiation, and the selection of several radiation sources for an intended application. The papaya industry in Hawaii, having been informed of the technical efficacy of radiation disinfestation, did not assign a high priority to the irradiation process as one of the alternatives to chemical fumigation. All the papaya packers instead opted for the double-dip hot water treatment which was to meet the EDB cutoff date of September 1, 1984 [11].

A comparison of the efficacy of irradiation vs thermal treatments of papayas is shown in Table 1.

Table 1. Efficacy of irradiation vs thermal treatments of papayas

	Irradiation	Thermal
Fruit Ripeness	Flexible	Controlled
Treatment Time	ca 40 min.	1-1/2 to 7 hrs
Effectiveness	100%	Larvae found in some treatment
Fruit Quality	Good	Lumpy texture, lack flavor
Shelf-life	Some extension	Improvement not known
Economics	ca. $0.10 - 0.15/kg	ca. $0.20 - 0.50/kg

An Opportunity missed by Hawaii to Build a Demonstration Irradiator

In 1985, the U.S. Department of Energy initiated the Agricultural Commodity Irradiation Demonstration Project under the Advanced Radiation Technology Program. The project was funded by the U.S. Congress to help the food industry gain experience in the technology of food irradiation. Six states were earmarked to build a demonstration irradiator to provide the opportunity for the local industry to participate in irradiating products that would benefit from irradiation such as quarantine treatment, shelf-life extension, and decontamination. The six states are: Alaska, Florida, Hawaii, Iowa, Oklahoma, and Washington.

Results of an economic feasibility study on irradiating Hawaii grown papayas as a quarantine treatment conducted by CH2MHill in 1986-87 and an environmental impact study (EIS) in 1987 showed the irradiation process to be very feasible and would be useful to the tropical fruit industry. Hearings on site selection and construction of the irradiator on the island of Hawaii (the Big island) were conducted in Honolulu and Hilo. Both favorable and unfavorable comments were expressed and heard. A number of people on the island of Hawaii including a state legislator objected to building an irradiator there. Somehow, the momentum to request funding for the irradiator for Hawaii slowed down considerably after these hearings. Since Congress stopped appropriating funds for the project after three years of funding, Hawaii missed the opportunity to build a demonstration irradiator. Among the six states, Hawaii is the state that could use the irradiator to demonstrate the use of irradiation as a quarantine treatment on papayas.

Current Interest in Irradiation in Hawaii

Hawaii is an agricultural state. Manufacturing industry in Hawaii is limited in scope due to a number of factors. In spite of the down-trend of the sugar and pineapple industry, diversified agriculture in Hawaii is viable and growing. However, sustaining many of the products from diversified agriculture such as tropical fruits, ornamentals, and herbs mentioned above rely on exports. With the prevalence of four species of fruit flies and other pests, an efficacious quarantine treatment must be available and used for many of these products. Irradiation has a number of advantages over other treatments. Therefore, Hawaii continues to have a high degree of interest in radiation technology both as a quarantine treatment for infested commodities and as a means of improving the safety and shelf-life of some selected products.

The objective would be to apply radiation technology to selected products that would benefit the industry in Hawaii and result in a sustained growth of the agricultural economy.

The rationale for using irradiation is that radiation technology is a tested and proven technology that could:
(a) help improve the handling and marketing of fresh commodities (i.e., as a quarantine treatment);
(b) allow development of export crops which were restricted by quarantine before, (e.g., mango and lychee);
(c) help improve public health by decontaminating poultry products (Hawaii has the highest incidence of Salmonellosis in the U.S.);
(d) provide an irradiation service to those organizations that have infested materials (e.g., library and museum);
(e) provide an opportunity to develop a new industry (e.g., wood-plastics), which might be useful because of the prevalence of ground and wood termites in Hawaii.

Prospect for Adopting Irradiation as a Quarantine Treatment Procedure in Hawaii

Irradiation, especially with a gamma source, has been shown to be superior to several thermal methods as a quarantine treatment for papayas and other tropical fruits in efficacy, product quality and economics, as demonstrated in previous studies, market tests of irradiated papayas and mangoes, and recent commercial marketing of irradiated strawberries and citrus in the United States.

The consensus reached recently by committee members representing the state planning office, the Department of Agriculture, other state agencies, and several industry groups was that Hawaii should pursue radiation technology in the next few years. Tentative work plans include (a) initiating planning of a pilot irradiator facility by specifying requirements, needs and criteria, and at the same time seeking input from irradiator manufacturers for their ideas; (b) seeking funding both at the federal and state level for the irradiator by exploring the possibility of a Hawaii/USDA joint venture for a shared facility for research and development; (c) constructing a pilot irradiator best suited for multi-purpose use by gaining support of potential user groups in the state; and (d) preparing plans for the management and utilization of the facility including phases of test marketing of Hawaii-grown products.

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EFFECTIVE IRRADIATION DOSES FOR QUARANTINE OF FRUIT FLIES AND OTHER ARTHROPODS

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The objective of this presentation is to compile and critique available information on the efficacy of using ionizing radiation as quarantine treatments against specific arthropods in agricultural commodities. Readers are directed to Burditt (1994) for a recent review of the history and development of irradiation as a quarantine treatment.

For a quarantine treatment to be effective sufficient dose must reach every individual of the quarantined pest to prevent reproduction. The ideal criterion for assuring lack of reproduction is immediate mortality of the pest after treatment; quarantine inspectors would not need to rely on assurances that any live organisms found would not complete development or would be sterile. Although moderate doses of ionizing radiation cause sterility to many quarantined pests, doses higher than those tolerable by many commodities are needed to provide immediate and complete mortality. Therefore, immediate mortality is not a viable goal with most quarantine pests. In 1986 an international group of researchers in the use of irradiation as a quarantine treatment suggested generic doses for groups of quarantined pests (Loaharanu 1992). A minimum dose of 150 Gy was adopted for tephritid fruit flies, and a minimum of 300 Gy was recommended for mites and insects other than fruit flies. The dose of 150 Gy should prevent emergence of normal adult fruit flies capable of flight. The dose of 300 Gy should produce sterility in any surviving insects or mites. Although these doses seem to be widely accepted as achieving their respective objectives (Heather 1992, Loaharanu 1992), some authors have expressed reservations.

For example, Brower and Tilton (1985) felt that doses >500 Gy may be necessary to sterilize some stored-product Lepidoptera of quarantine significance.

Doses for Fruit Flies to Achieve Quarantine Security

Balock et al. (1966) estimated doses of gamma irradiation from a cobalt-60 source required to prevent 99.9968% adult emergence ($ED_{99.9968}$) in oriental fruit fly, Bactrocera dorsalis (Hendel), and the melon fly, B. cucurbitae (Coquillett), in fruits. $ED_{99.9968}$ for oriental fruit fly immatures in papaya, avocado, and miscellaneous fruits were estimated to be 206, 219, and 280 Gy, respectively. Seo et al. (1973) presented data showing that the above $ED_{99.9968}$ estimates may not be excessive; at 218, 225, and 244 Gy, 3 of 73,618, 2 of 76,850, and 17 of 130,156 oriental fruit fly immatures in papaya emerged as adults which lived for up to 24 days. Also, at 225 Gy, 2 of 110,772 Mediterranean fruit fly, Ceratitis capitata (Wiedemann) immatures in papaya emerged as adults. On the other hand, in additional tests by Seo et al. (1973) no adults emerged from estimated totals of 617,897, 217,690, and 109,075 oriental fruit, Mediterranean fruit, and melon fly immatures, respectively, irradiated at minimum doses of 214-291 Gy. Additionaly, no adults emerged from an estimated total of 371,843 melon fly immatures irradiated at a minimum dose of 209 Gy in bell peppers.

A dose of 150 Gy applied to carambolas infested with an estimated 18,000 third instar oriental fruit flies in Malaysia prevented adult emergence (Vijaysegaran et al. 1992). However, emergence was only 9.8% in the control which casts doubt on the viability of the insects used in the test. Low humidity or other unfavorable conditions during the pupal stage may cause low levels of emergence which might affect treated insects more than untreated ones. A dose of 100 Gy prevented adult emergence of 131,148 five day-old oriental fruit fly in 250-300 g 'Carabao' mangoes (Manoto et al. 1992). However, infestation levels were very high (a mean of 117.1 larvae emerged from irradiated mangoes; no estimate is given on the number which may have died within the mango).

Komson et al. (1992) achieved better than probit 9 security at the 95% confidence level with a dose of 150 Gy applied to 5-day old oriental fruit fly larvae in 'Nang Klangwan' mangoes. An estimated 173,042 larvae were treated, 145,912 pupated and one adult emerged. Adult emergence was 80% in untreated fruits, and the infestation level was high (115 pupae per mango).

The Queensland fruit fly, _Bactrocera tryoni_ (Froggatt), and _B. jarvisi_ seem to be among the most susceptible of the fruit flies studied to irradiation. No adults emerged from any of the trials listed in Table 1.

Burditt and Hungate (1988) irradiated 133,978 cherries infested with western cherry fruit fly, _Rhagoletis indifferens_ Curran, at a mean dose of 97 Gy with one adult with vestigial wings emerging from an expected population of 15,812 adults.

The Mediterranean fruit fly was more tolerant of irradiation than three species of _Anastrepha_ in mangoes in Mexico (Bustos et al. 1992). Five of 5,268 Mediterranean fruit fly larvae emerged as adults from mangoes irradiated at 150 Gy. However, in a subsequent large-scale test, no adults emerged from 100,854 Mediterrenean fruit fly third instars irradiated in mangoes at 150 Gy.

Generally, emergence of adults of Anastrepha spp. from irradiated immatures has been prevented at ≤150 Gy (Table 2). However, von Windeguth and Ismael (1987) found one unexpanded adult Caribbean fruit fly, A. suspensa (Loew), emerged from an estimated total of 1,966 larvae in infested grapefruits irradiated with a mean dose of 225 Gy (range 152-298). This adult apparently had pupated within the fruit load, not crawling down into the pupal collection bin as expected, as no pupal case was found. This leads one to suspect that other larvae might pupate within the fruit load and adults emerging may not be collected. Von Windeguth and Gould (1990) mentioned an unpublished test where a dose of 150 Gy to Caribbean fruit fly infested grapefruits prevented adult emergence of 114,606 immatures.

In summary, it seems that the recommended generic dose for fruit flies, 150 Gy, would suffice for B. tryoni, B. jarvisi, and the Anastrepha spp. studied. However, there are some data indicating that 150 Gy may not prevent 99.9968% emergence of normal appearing adults at the 95% confidence level for C. capitata, B. dorsalis, and B. cucurbitae.

Doses for Arthropods Other than Fruit Flies

For codling moth, Cydia pomonella (L.), a quarantine treatment must be effective against eggs and larvae, including diapausing fifth instars. Burditt & Moffitt (1985) estimated that projected doses necessary to prevent 99.9968% emergence of adult codling moth from fifth instars were slightly greater for diapausing larvae irradiated on fiberboard strips (225 Gy) than nondiapausing larvae in apples (206 Gy). The dose estimate was reduced to 145 and 137 Gy for diapsusing and nondiapausing fith instars, respectively, if the criteria was prevention of 99.9968% emergence of normal-appearing adults. However, Burditt (1986) found that diapausing codling moth larvae were more susceptible to irradiation than nondiapausing larvae in walnuts. A dose of 230 Gy was estimated to prevent adult emergence of nondiapausing larave. Burditt & Hungate (1989) exposed 79,540 nondiapausing larvae of all instars (mostly second, third, and fourth) to 153 Gy in apples with no adult survivors. More research subjecting large numbers of fifth instar codling moth, both diapausing and nondiapausing, to irradiation needs to be done before it can be concluded that quarantine security of codling moth can be accomplished with irradiation. However, it appears that this can be accomplished at doses $\leq$300 Gy.

Mango weevil, Sternochetus mangiferae (Fabricius), larvae, pupae, and adults may be present in marketed mangoes. High irradiation doses would be necessary to kill the adults. At 850 Gy only 68% mango weevil mortality occurred (Milne et al. 1977). However, the authors felt that 500 Gy would be sufficient to prevent adult emergence from the mango seed (Milne et al. 1977). Seo et el. (1974) found no successful reproduction in 30 pairs of weevils irradiated with 50 Gy; however, 14 sterile eggs were laid and one male produced sperm. Irradiation at 298-339 Gy prevented emergence of an estimated total of 1,951 mango weevil larvae, pupae, and adults from infested mangoes (Heather & Corcoran 1992). More confirmation is needed before an irradiation dose that prevents mango weevil reproduction is accepted.

Any stage of sweetpotato weevil, Cylas formicarius elegantulus (Summers), may be present in marketed sweet potatoes. Sterility of the weevil infesting sweet potato was not achieved by 270 Gy (Sharp, J. L., personal communication).

Hatch of about 6,500 older Fuller rose beetle, Pantomorus cervinus (Boheman), eggs was prevented on lemons by 150 Gy (Johnson et al. 1990). After preliminary research, Halfhill (1988) felt that quarantine security of asparagus aphid, Brachycorynella asparagi (Mordvilko), on asparagus could be achieved by 100 Gy at 20°C.

For irradiation to provide quarantine security of mites, sterilization, if not death, must be assured for all stages. Only sterile eggs were laid from a total of 1,390 eggs, larvae, and adults of twospotted spider mites, Tetranychus urticae Koch, irradiated with 300 Gy. Ignatowicz (1992) studied the effects of irradiation on reproduction of three species of mites. Doses between 180-500 Gy were needed to prevent reproduction of irradiated deutonymphs and adults. A dose of 2,110 Gy was required to cause 100% mortality of the mold mite, Tyrophagus putrescentiae (Schrank), within three days.

Brower and Tilton (1985) reviewed irradiation doses necessary to cause sterility in stored-product pests, including some of quarantine significance. Several species, such as the depressed flour beetle, Palorus subdepressus (Wollaston), and various Lepidopterans, could still reproduce after doses of ≥300 Gy. For the most part these studies were done with low numbers of insects; doses to satisfy probit security requirements would probably be greater.

I do not believe that a generic dose of 300 Gy for all arthropods other than fruit flies should be recommended considering the variation in arthropod types and life stages that are quarantined and the results of certain studies. Quarantine security of some non-fruit flies might be achieved with lower doses. 300 Gy may not be sufficient to achieve complete sterilization of some arthropods.

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Table 1. Irradiation treatments of fruits infested with <u>Bactrocera</u> <u>tryoni</u> and <u>Bactrocera</u> <u>jarvisi</u> in which no apparently normal adults emerged

Fruit host	Fruit fly stage	Dose (Gy)	Number treated	Reference
<u>B</u>. <u>tryoni</u>				
Avocado	3rd instar	75-100	40,030	Rigney & Wills (1985)
Cherry	3rd instar	75-100	2,318	Jessup (1990)
Mango	Egg	74-100	208,134	Heather et al. (1991)
Mango	3rd instar	74-100	138,635	Heather et al. (1991)
Valencia orange	Egg	75	31,452	Jessup et al. (1992)
Valencia orange	Young larvae	50	40,218	Jessup et al. (1992)
Valencia orange	Young larvae	75	23,839	Jessup et al. (1992)
Valencia orange	Old larvae	75	220,328	Jessup et al. (1992)
Granny Sm. apple	Egg	75	12,063	Jessup et al. (1992)
Granny Sm. apple	Young larvae	75	12,225	Jessup et al. (1992)
Granny Sm. apple	Old larvae	75	128,373	Jessup et al. (1992)
Fuerte avocado	Egg	75	38,463	Jessup et al. (1992)
Fuerte avocado	Young larvae	50	20,376	Jessup et al. (1992)
Fuerte avocado	Young larvae	75	20,376	Jessup et al. (1992)
Fuerte avocado	Old larvae	75	213,638	Jessup et al. (1992)
Floridade tomato	Egg	50	10,791	Jessup et al. (1992)
Floridade tomato	Egg	75	10,791	Jessup et al. (1992)
Floridade tomato	Young larvae	50	11,383	Jessup et al. (1992)
Floridade tomato	Young larvae	75	11,383	Jessup et al. (1992)

Floridade tomato	Old larvae	50	2,891	Jessup et al. (1992)
Floridade tomato	Old larvae	75	2,891	Jessup et al. (1992)
Supreme cherry	Egg	75	1,389	Jessup et al. (1992)
Supreme cherry	Young larvae	75	2,898	Jessup et al. (1992)
Supreme cherry	Old larvae	75	1,484	Jessup et al. (1992)
B. jarvisi				
Kensington mango	Egg	74-100	110,935	Heather et al. (1991)
Kensington mango	3rd instar	74-100	153,814	Heather et al. (1991)

Table 2. Irradiation treatments of fruits infested with Anastrepha spp. in which no apparently normal adults emerged

Anastrepha species	Fruit host	Fruit fly stage	Dose (Gy)	Number treated	Reference
suspensa (Loew)	Mango	3-4 day larvae	50	64,668	von Windeguth (1986)[1]
suspensa	Carambola	immature	50	>100,000	Gould & von Windeguth (1991)
serpentina (Wiedemann)	Mango	3rd instar	100	105,252	Bustos et al. (1992)
ludens (Loew)	Mango	3rd instar	100	101,794	Bustos et al. (1992)
obliqua (Macquart)	Mango	3rd instar	100	100,400	Bustos et al. (1992)

[1]In another test, one apparently normal adult emerged from an estimated population of 25,363 third instars in mangoes irradiated at 55 Gy.

Questions, Answer, Comments, and Discussions on Dr. Guy Hallman's Presentation

Comment: You, mention number of cases of adult emergence. Are these adults capable of flight? It is my understanding, going back a few years, that the criterion considered for application of irradiation disinfestation work is inability to fly. In the case of fruit flies, that affects sexual sterility, which is taken for granted.

Response: Most of these data came out of Stan Seo's work and he didn't mention it in the publication. He did mention that the longest surviving adults might have lived 24 days; whether they were able to fly or not wasn't mentioned. We need to decide what is the criterion for rejecting a treatment; what shape of an insect would you accept?

Comment: You mention that for most other insects (except fruit flies) you have to look at doses on a specific basis. You say that we don't have data that show that 300 Gy is enough, or not enough.

Response: Oh, Yes. There are data; there are data showing that stored product pests weren't sterilized at doses quite a bit above 300 Gy and other showing mites not being sterilized at 450-500 Gy.

Question: Did you do the experiment yourself on this sort of adult emergence at that dose. If that is the case, what type of fruit fly and what type of commodity?

Response: No, I didn't do any of this research I presented here. It is all culled from the literature and you are correct, we are not able to tell exactly what was done in some cases. For example, for some of the older studies, were they really getting the doses they thought they were getting? That is something we have to sit down and look at carefully.

Comment: Exactly. We should believe just like that; we certainly need to criticize those studies more carefully.

Comment: Again, you mention the data from Bustos et al. (1992)and that was from a preliminary paper that was written in 1991. I have a copy in my briefcase and, the revised version of that paper was written in December, 1993. One of the questions you mention was why they selected 150 Gy for their 100,000 insect test. The reason is that though they already had some data that showed five emerging adults at 150 Gy, the data from lower doses, 120 Gy, 100 Gy and lower, when plotted on a curve, showed that 150 Gy should be enough. Therefore, they selected that rather than some other dose. Also, they felt that five flies emerging was due to some unexplained deviation. Since then, in 1993, they re-did the irradiation at 150 Gy and again got zero emergence; so they are in the process of writing this up in a final paper.

Comment: It's good to know if they can come to an explanation why they got five adults.

Burditt: On that business, you cannot combine the 5,000 initial test with the five survivors with the 100,000 on a subsequent test, because they were completely different conditions. As far as, Stanley Seo's (1973) data where he had the seventeen survivors, we went over those data, and there was indication that with that particular experiment with the 17 survivors, that batch of infested papayas was not irradiated at the dose that it was supposed to have been. Also, with some of the work that Jack Balock et al. (1966) did, we had Medflies emerging from a test with melon fly infestation. And another test we had Medflies emerging from a test of Oriental fruit flies, so obviously it was contamination that was taking place somewhere in the test cycle. And in one of the experiments that Don von Winduguth and I did in Miami, we had fly pupae and held them for emergence, and we did get emergence from infested grapefruit. They were house flies that emerged from a Caribbean fruit fly experiment. And, as far as these tests that Puongpaka did in Thailand and the test that Manoto et al. (1992) did in the Philippines where they had populations of over 100 larvae per fruit, that's a 1000 fruit that they have to test, and in the experimental facilities that they have, if they went down to a lower population per fruit you'd have to test 10,000 fruit and their economy isn't such that they can afford to test 10,000 or more fruit in trying to meet these requirements.

Comment: This all has to be taken into account, and we can't jeopardize our agriculture by some test that was maybe not quite up to par either. As far as those five larvae, I could go along with this explanation that something was wrong, but, I think that if you can't find an explanation, you really have to include any insect that you get back at that particular dose.

Perhaps during one part of the year when they did this irradiation, certain conditions favored survival of some of those larvae. When they did the large scale test in a different time of the year and it might have been the least favorable time for survival. These tests need to be done over all ranges, all conditions, bringing in mangoes from all different growing regions, if you don't know what type of specific conditions might exist which might favor survival. This is what happened, I think, with the double dip in papaya. The blossom end-defected papaya, to be in such a high proportion that they were, had to be there for awhile before, but they weren't used in the research. The scope of the research may not have been broad enough to bring in those papayas. Had they been brought in from the start they would have realized from the start that this defect existed. A quarantine treatment has to be to be confirmed over the whole range where the commodity is grown.

Burditt: When I was working on a hot water dip for papayas using EDB in hot water, I ran 20 some tests with no survivors and the 28th test I had a hundred survivors. Now, obviously, something was wrong with that particular test.

Comment: I am Jim Fons from APHIS. I'd like to thank Dr. Hallman for some moral support. I've been going to these meetings now for I don't know for how many years, probably more than I care to admit, and it's the first time that I have not been the only target of the arrows that are shot at me. I don't want to refuse to read any of the data that is presented here, but I think it does illustrate very well the hazards of changing the standards. It is a very high standard; we all admit that it is. Whether it's too high or too low, it's always going to be subject to some kind of discussion, but I think the conversations, the data that we showed today, although I believe that they can be explained, are in need of explanation.

SUITABILITY OF IRRADIATION DISINFESTATION ON PRODUCE PREVIOUSLY DEEMED TO BE UNSUITABLE OR SENSITIVE

by

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Suitability of Irradiation Disinfestation for Produce Previously Deemed to be Unsuitable or Sensitive

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Introduction

There has been extensive research on various aspects of low-dose irradiation on produce commodities. The difficulty with assessing the effect of irradiation disinfestation on these produce items is that the research literature is sometimes old, sparse for some commodities not as detailed as would be preferred, or is contradicted by other research or experience. Additionally, the research often investigated the effect of irradiation at the dose range required to control mold or bacterial spoilage, rather than at the lower doses required for disinfestation. This research approach is largely responsible for the conclusion that many perishable products can not be irradiated successfully.

With some of these commodities, varietal differences seem to be quite significant. Unfortunately, many researchers do not indicate the varieties they investigated. Some of the older research may have used out of date varieties; newer varieties may be more commercially significant now.

Since the research on many of these commodities is older, the reporting of the dosimetry is often not clear. It is not always possible to determine if the researcher was referring to a minimum dose or an 'average' dose. In some cases however, when the type of equipment is noted, the dose range can be estimated.

These comments are not intended to criticize the researchers but to help the reader understand why exacting conclusions are not always possible. When new irradiation research is being planned, it would be useful to improve the dosimetry, to more carefully control and report on pre- and post-harvest conditions, and to ensure fruit quality indicators are reported.

To be really useful, the research literature must also be assessed from the point of view of commercial applicability. In a commercial process, most of the product in a carton or a pallet load would receive a higher dose than the minimum. The commodity must tolerate a maximum dose that is 2 to 3 times higher than the minimum. This means if the pest problem is fruit flies, the commodity should tolerate 0.30 - 0.45 kGy. For other pests, as a general rule, the product should tolerate 0.60 - 0.90 kGy.

If commodity sensitivity to radiation is such that the maximum to minimum dose ratio must be tighter than indicated above, the economics of commercial irradiation may become difficult. In that case, combination treatments should also be considered. They can work very well, but require more resources both for research and to implement commercially. With the exception of strawberries, irradiation combination treatments have not been well researched or commercially applied. Practically speaking, refrigeration is not really a combination process when the irradiation of perishable products is discussed. If refrigeration is required for untreated commodities, refrigeration will still be required after irradiation.

Pest Control

While produce can be infested with a variety of pests, it may not be necessary to exactly establish the minimum dose for each pest. The reaction of pests to radiation, in general, is rather similar. For this reason, minimum doses have been established internationally for many pests; they are slightly higher than the exact minimum dose required to control the pest. In other cases, where the product can easily withstand the higher dose, some regulatory authorities simply set the allowed treatment at a minimum dose so high that any pest would be controlled or killed, given what is known about the reaction of living things to radiation.

When irradiation disinfestation is discussed, the term 'control' is more often used rather than 'kill'. While irradiation at disinfestation dose ranges results in a sexually sterile pest, the treatment may not necessarily kill all life stages of the pest, or may not kill it immediately. In this paper the term 'disinfestation' is used to indicate pest control. In their 1989 position paper, The North American Plant Protection Organization examined this issue and indicated that the inability to reproduce can be sufficient criterion for quarantine security. Since there is no method currently available to identify irradiated insects however, and since expensive quarantine measures may be triggered by the presence of quarantine insects in traps or other locations, a second criterion of the inability of the pest to fly or move to host plants is required to permit the use of irradiation as a quarantine treatment. Canada, the United States and Mexico are signatories to this agreement (NAPPO, 1989).

The International Consultative Group on Food Irradiation, a group that operates under the aegis of the three United Nations organizations involved in food irradiation (FAO, IAEA, WHO) examined the research and gave general minimum dose guidelines to control pests in a wide variety of commodities (ICGFI, 1988). Fresh fruits subject to infestation by Queensland fruit fly should be exposed to a minimum dose of 0.075 kGy. Fresh fruits subject to infestation by *Tephritidae* should be exposed to a minimum dose of 0.15 kGy. Produce commodities that are host to coddling moth, (*Cydia pomella*) should be exposed to 0.25 kGy. Fresh fruits subject to exposure by other insects pests should be exposed to 0.30 kGy.

Apples:

Various varieties of apples have been commercially irradiated and sold in the People's Republic of China for several years. Researchers there indicate that a dose of 0.40 kGy and a storage temperature of 2°C resulted in 10 months shelf life (Xu et al, 1993). Wang et al (1993) reported the results of several tests by Chinese researchers with different varieties of apples at various storage temperatures. The apples, all irradiated at less than 0.5 kGy, were generally considered ave good keeping qualities. In a study of 'Golden Delicious' apples kept at room temperature autumn in Beijing), apples irradiated up to 0.9 kGy stored very well. After 6 months 37% of control fruit was good quality, 76% of fruit irradiated at 0.5 kGy was good quality and 73% of fruit irradiated at 0.9 kGy was good quality. 'Red Delicious' apples were irradiated in Washington State between 0 and 1.0 kGy. Although irradiation was reported to slightly increase softening and reduce acidity, all apples surpassed the export standard for firmness after 11 months (Olsen et al, 1989). 'Red Delicious' apples were also irradiated to control San Jose scale (*Quadraspidiotus perniciosus*) The results at 0.60 kGy seemed inconclusive from a disinfestation viewpoint, but no radiation damage to the apples was reported at that dose (Angerilli and Fitzgibbon, 1990).

Conclusion: Apples can withstand irradiation disinfestation with resulting improved shelf life.

Asparagus:

Asparagus is sometimes noted as having inconsistent results when irradiated. University of Michigan researchers irradiated asparagus at doses between 0.01 - 1.0 kGy noting that irradiation slightly retarded spear lengthening but had little or no effect on water loss, color or texture (Markakis and Nicholas, 1972). The Department of Energy in the U.S. exhibited several irradiated fruits and vegetables a few years ago at an IFT meeting; the asparagus irradiated at a minimum dose of 0.25 kGy was firm, green and fresh looking. The Council for Agricultural Science and Technology (1984) said that irradiation at 0.05 kGy - 0.15 kGy extends shelf life by inhibiting elongation and curvature of spears.

South African researchers have investigated the irradiation of white asparagus, a product that is not widely grown or fresh marketed in North America. They reported 32 days of marketable life after 1.5 kGy irradiation and 2°C storage. At 6°C storage, a more likely storage temperature in retail or at home, white asparagus was still marketable after 28 days (Broderick et al, 1983).

Conclusion: Asparagus can probably withstand irradiation disinfestation. Shelf-life will probably be similar to or slightly longer than unirradiated asparagus.

Avocados:

Most writers generally note that irradiation harms the quality of avocados, or that the effect is highly variety specific. The problem seems to be that disinfestation occurs at a dose lower than avocados can tolerate. Irradiation, however, can assist to extend shelf-life at very low doses. Chilean researchers looked at two varieties, 'Fuerte' and 'Hass', picked early in the season or late, hot-dipped at 46°C or not, individually wrapped in PVC film or unwrapped, irradiated at 0.025, 0.050 and 0.10 kGy or not irradiated and stored at 7°C or room temperature. They examined the fruit quality at 0, 20, 30, 40 and 50 days. Both varieties picked early in the season, hot dipped, wrapped and irradiated at 0.025 kGy lasted best over other treatments. For Fuerte variety, at 40 days storage over 98% of fruit were sound. For Hass variety at 40 days storage 55% of fruit were sound. The early picked, hot dipped, wrapped fruit, irradiated to 0.050 kGy also did well, although less well than at 0.025 kGy. Fruit irradiated at 0.10 kGy were of poorer quality than controls. Late picked, irradiated fruit also did less well, but all irradiation treatments were also combined with hot-dipping which is deleterious to more mature fruit (Karmelic et al, 1985). In another study avocados were treated wrapped in polyethylene (Saran Wrap), irradiated with 0.075 kGy, stored at 15°C and 70%RH for 24 days in good condition (Munoz Burgos, 1989).

Conclusion: While these reports are interesting from a food quality viewpoint, it is important to note that the doses reported to be effective for avocados are one order of magnitude less than what is required for disinfestation. It should also be noted that PVC film is not recommended for irradiation applications, although it may not have been a problem at these low doses. It does not appear likely that avocados will tolerate the radiation doses required to disinfest them.

Blueberries:

Recent work with 'Climax' blueberries in Florida (Miller et al, 1994, a and b) during the 1991 and 1992 seasons showed that change in berry quality was dose related. They indicated berry quality was acceptable below 0.75 kGy but indicated that above 0.75 kGy berry softening, texture and flavor changes could be expected.

Canadian researchers looking at the irradiation of six blueberry cultivars reported varietal differences. They looked at doses of 1 - 5 kGy and reported softening in two of six varieties at 1 kGy, although at that dose the effect was reported to be minimal. An inconsistent color change was noted with a slight trend away from the blue scale to green (Eaton et al, 1970). Blueberries irradiated between 1.5 and 3.0 kGy (a dose quite a bit higher than required for disinfestation) exhibited softening which the researchers noted was offset by dipping the blueberries in a 0.5% Ca^{2+} solution (from $CaCl_2 * 2H_2O$) for 1 hour before irradiation (Markakis and Nicholas, 1972).

Conclusion: Blueberries can be irradiation disinfested but care should be taken to minimize the maximum dose. Blueberries will exhibit softening and flavor changes as the dose approaches 1 kGy.

Cherries:

Burditt and Hungate (1988) considered that cherries could be irradiated against the western cherry fruit fly at doses well below the 0.5 kGy to 2.0 kGy dose that was determined to cause adverse effects in several cherry cultivars. USDA researchers (Drake, et al, 1993) in as-yet-unpublished research looked at the irradiation of 'Rainier' sweet cherries, a light colored cherry. They looked at irradiation alone (0.0, 0.1, 0.2, 0.3, 0.4, 0.5, and 1.0 kGy) and irradiation with gibberellic acid. (Gibberellic acid is sprayed on trees at color break between green to yellow. It delays harvest by slowing color development, adds 25% to Vitamin C content and makes the harvested cherries crunchier.) They noted a 10% loss of firmness because of the irradiation treatment at the 1.0 kGy dose only. They reviewed the research on the irradiation of cherries, reporting that 0.25 kGy controlled coddling moth and that 'Bing' cherries withstood up to 0.60 kGy. They also reported Australian research that indicated 'Bing' and 'Lambert' cherries withstood doses higher than 0.75 kGy.

On the other hand, California 'Bing' cherries irradiated 1 day post-harvest at 0.60 - 0.80 kGy and stored for 11 days, showed greater shrivelling, softer sensory scores and flavor differences (irradiated fruit scored as sweeter tasting). Manual firmness testing, skin color and the degree of browning did not differ from controls (O'Mahoney et al, 1985). In cherries irradiated between 1.0 to 8.0 kGy cherries were softer than controls, as would be expected at such a high dose, but the use of 0.5% Ca^{2+} solution as indicated for blueberries controlled softening, even at the high doses used. No advantage was seen in combining a hot dip of 46°C - 50°C. for 4 minutes plus irradiation of 1.0 or 2.0 kGy (Markakis and Nicholas, 1972).

Conclusion: Cherries will withstand the dose required to control fruit flies. Most cherry varieties will also withstand the 0.75 kGy maximum dose required to control coddling moth with some minor effects on fruit quality in some varieties if the dose is allowed to approach 1 kGy. Some varieties may require a maximum dose of 0.60 kGy to avoid fruit softening.

Cut Flowers:

Research on irradiation disinfestation of cut flowers has not been as extensive as for other perishable commodities. The Joint FAO/IAEA Division reported the results of cut flower research co-ordinated in the Netherlands by Van de Vrie (1986). The following pests were determined to require 0.2 kGy to inactivate or sterilize: *Frankllininella pallida; Spodoptera exigua; Clepsis spectrana; Myzus persicae; Liriomyza trifolii.* Twospotted spider mite, (*Tetraranychus urticae*) required a dose of 0.35 kGy to inactivate or sterilize both the developmental and adult stages. At the doses tested, the effect on the flowers varied by species and cultivar; in many cases no effect on the flowers was seen. For carnation, rose and freesia, an increase in vase-life was seen.

Piriyathamrong et al (1985) reported that irradiation at 1.5 and 2.0 kGy eliminated thrips in orchids with a resulting vase life of 6-8 days. This represented a decrease in vase life of approximately 8-10 days. Goodwin and Wellham (1990), reported on the effect of irradiation on the twospotted spider mite. In that work, 0.3 kGy eggs either did not hatch, or, if the eggs did hatch, the ensuing females were sterile.

Conclusions: Some cut flowers may be irradiation disinfested. Since results are variety specific, more research is required.

Grapes:

Grapes are an important crop, significant for their need to be disinfested for export and because they can be infested with a mite, among other pests. A higher dose is required to control mites. Grapes are almost always said to be sensitive to radiation. Several researchers indicate that the response to irradiation depends on the grape variety. Other factors such as stage of ripening will also influence post-irradiation quality and shelflife (Thomas, 1986). Research on grapes was almost entirely intended to determine if irradiation could control mold spoilage (at doses often higher than required to control pests). Additionally, the effect of irradiation on grapes was assessed in the context of SO_2 fumigation of grapes, a treatment that is not always preferred now as sulphite sensitivity becomes better understood. These factors, with the inconsistent results reported with different varieties, make firm conclusions difficult.

Maxie (1971) indicated grapes will tolerate 0.25 - 0.50 kGy. Josephson and Peterson (1983) reviewed one paper that indicated 'Hoanes' grapes when irradiated at 50%-80% ripeness to 2.0 kGy exhibited extended shelf life by two weeks. Greek researchers tested two varieties of table grapes ('Razaki' and 'Sideritis') with doses of 1.0 - 5.0 kGy and refrigeration storage at 0°C. The grapes irradiated to 2.0 kGy stored well (good marketable quality after 80 days; controls spoiled after 35 days). Irradiation at that dose did not affect color (Saravacos and Macris, 1963). Thomas (1986) reviewed the work of several researchers, often reporting good results at less than 1 kGy.

Conclusion: The response of grapes to irradiation should be assumed to be variety specific. Cool storage temperatures will be critical in maintaining fruit quality. Grapes will probably withstand a dose that meets the criteria described above for the commercial requirements for controlling fruit fly infestations. Depending on variety, they may withstand the dose required to control mites or other pests. The grape varieties that require disinfestation for mites should be tested for tolerance to 0.60 to 0.75 kGy and with combination treatments.

Kiwi:

Kiwi harvested in September were irradiated at 0.6, 1.8 and 3.6 kGy and stored in a room cooled by night air in autumn (Shandong Province). By late December, 91.4% of control fruit were normal and 95.1% of fruit irradiated at 0.6 kGy were normal. 92.7 % of fruit irradiated at 1.8 kGy were normal and of fruit irradiated at 3.6 kGy, only 76.9% were normal (Yu, et al, 1993).

Conclusion: Since disinfestation can be assumed to require less than 1 kGy, it can be concluded that kiwi can be radiation disinfested and that good storage life could be a side benefit.

Lemons and limes:

Johnson and co-workers (1990) irradiated lemons at very low doses (50-150 Gy) to control Fuller Rose Beetle eggs. They reported variable damage to the lemons to a maximum of approximately 6% (rind damage and decay). Irradiation at this dose, however, was reported to be less damaging than methyl bromide. Note that the maximum dose used in this study is the minimum dose required for control of fruit flies.

Maxie, 1971, studied transportation injury in a number of irradiated fruit. His report, also relates effects seen due to irradiation softening. He indicated that limes did not tolerate a higher dose than 0.25 kGy. Florida 'Bearss' lemons were studied for possible delay of stem-end decay. They were irradiated at 0.50, 1.0 and 2.0 kGy. Only the 2.0 kGy dose was noted as reducing spoilage, but the researchers did not note radiation sensitivity problems at the other doses. In another study, limes bought from market and wrapped in polyethylene (Saran Wrap) before irradiation at 0.50 - 1.0 kGy then stored at 25°C showed accelerated deterioration (Avadhani et al, 1985). The use of an overwrap could have been part of the problem; it may have accelerated mold development, a common reason for spoilage of these fruits.

Conclusion: Lemons and limes are probably sensitive to irradiation at the doses required for pests other than fruit flies. They should withstand irradiation disinfestation for fruit fly. To minimize problems with sensitivity, efforts should be made to lower the maximum to minimum dose ratio to as close to 2:1. as possible

Lychee (Litchi):

In one of the few combination treatments reported, lychees hot dipped at 50°C for ten minutes and irradiated at 2.0 kGy showed no significant composition changes. No other problems were noted (Beyers, et al, 1979). Irradiated (1.0 kGy), refrigerated (5°C) lychee stored well for 16 days as compared to 4 days for control in work by Ilangantileke (1993). Litchi irradiated at 0.5 kGy and stored at 2°C had a shelf-life of 3 months in another study (Yu, et al, 1993).

Conclusion: From these reports, it can be concluded that pests associated with litchi can be controlled by irradiation and that a better storage life may also result.

Raspberries and Blackberries:

Raspberries have also been mentioned as a fruit that is too sensitive to radiation, causing softening that hastens mold development. These reports have generally been based on observations of small test irradiations. We observed similar results in a very small test of raspberries at Nordion with raspberries irradiated between 0.50 and 1.0 kGy. A small quantity of raspberries were irradiated at Vindicator in Florida (< 1 kGy). The fruit was Chilean and was therefore 2-3 days post harvest with poor temperature control in transit. The raspberries did exhibit extended shelf-life (with irradiation and refrigeration) but they were also softer after irradiation (Rayburn, 1993). Rayburn noted that raspberries must not be subjected to any physical pressure from the packaging materials.

Maxie (1971), however, whose much more extensive work included an assessment of post-irradiation transportation quality, indicated raspberries tolerated up to 1 kGy. French researchers indicated that raspberries and blackberries tolerated up to 1.5 kGy as long as handling of the fruit is kept to a strict minimum (Vidal. 1963). Australian researchers (Markus et al, 1985) in a reasonably large study, also had positive results. They took fresh Tasmanian berries (no variety given) did room temp irradiations in O_2 and N_2 between 0 and 5.0 kGy followed by 4°C storage. The best results were reported with berries irradiated at 3.0, 4.0 and 5.0 kGy, doses that are surprisingly high. Control berries were unsuitable for sale at 17 days.

This result must mean that either these berries, or the conditions, or the spoilage organisms were different from what we see in Canada where spoilage usually occurs in less than 5 days. In this research the combination effect of N_2 was not seen until the longest storage times at the highest dose.

It is possible that Australian raspberries bear more resemblance to North American blackberries, which are less delicate. Vindicator irradiated Mexican blackberries 2 days post harvest with poor temperature control post harvest. They did not show softening and held up very well after irradiation (< 1 kGy) under refrigeration for two weeks (Rayburn, 1993).

Conclusion: In practical experience, the keeping quality of raspberries varies considerably from season to season; they are one of the shortest shelf-life fruits. It is fair to conclude that raspberries may have a reasonable tolerance to disinfestation doses, especially if the pest is fruit fly and/or the maximum dose can be kept to less than 0.50 kGy. This conclusion is very tentative; companies interested in commercial scale raspberry irradiation are advised to retest under local growing conditions.

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IRRADIATION ON QUALITY OF HORTICULTURAL COMMODITIES

AND

EVALUATION OF PHYTOTOXICITY OF IRRADIATED HORTICULTURAL COMMODITIES

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Evaluation of Phytotoxicity of Irradiated Horticultural Commodities

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Most fresh fruits and vegetables will tolerate irradiation at 0.25 kGy with minimal detrimental effects on quality. At doses between 0.25 and 1.0 kGy, some commodities can be damaged. The relative tolerance of fruit fruits and fruit-vegetables to ionizing radiation at doses below 1.0 kGy is presented in Table 1. A review of the literature on the effect of irradiation on the resulting market quality of fresh fruits and vegetables is presented below and summarized in Table 2. Also included are tables from two published reviews regarding the maximum tolerated irradiation dose by fruits and vegetables (Tables 3 and 4).

Apple. Radiation damage was not apparent on 'Red Delicious' apples treated with a dose of 0.05, 0.15, or 0.3 kGy (Angerilli & Fitzgibbon 1990). Olsen et al. (1989) demonstrated that 'Red Delicious' apples could be irradiated at 0.2 to 1.0 kGy and maintain acceptable condition and quality during 11 months in storage.

Avocado. Akamine & Goo (1971) found that the shelf life of preclimacteric avocado fruits was adversely affected at all rates of irradiation from .03 to 0.5 kGy. Balock et al. (1966) found Hawaiian-grown 'Nutmeg', 'Fuerte', 'Coban', 'Tsutsumi', 'Nabal', 'Beardslee', 'Johnson', 'Kahulu', and 'Lehua' avocados to be extremely sensitive to 0.25 kGy, and Jessup et al. (1992) found damage at 0.1 kGy.

Banana. 'Williams' bananas suffered skin russeting at 0.5 kGy but no impairment of flavor (Balock et al. 1966). Green bananas compared favorably with control fruit in terms of color, flavor, and texture following irradiation at 0.5 kGy (Ferguson et al. 1966). Irradiation of preclimacteric 'Giant Cavendish', 'Red', 'Fill Basket', and 'French Plantain' bananas at doses above 0.5 kGy resulted in severe skin discoloration and fruit splitting (Thomas et al. 1971).

Blueberry. Irradiation at 1.0 kGy significantly increased darkness and redness in 'June' and 'Coville' and redness only in 'Dixi' highbush blueberries (Eaton et al. 1970). Significant adverse effects were also noted on 'Dixi' and 'Coville' berries (Eaton et al. 1970). Eaton et al. (1970) found no effect of 1.0 kGy on darkness, redness, and soluble solids of 'Rancocas', 'Bluecrop', and 'Jersey' blueberry cultivars. 'Climax' rabbiteye blueberries tolerated dosages up to 1.0 kGy without significant increases in softening and loss of flavor (Miller et al. 1994).

Carambola. Carambola phytotoxicity tests at doses ranging from 0.05 to 1.5 kGy indicated that no observable damage occurred at levels between 0.05 and 0.5 kGy (Gould & von Windeguth 1991). However, Vijaysegaran et al. (1992) found 'B10' carambolas to be damaged at doses in excess of 0.2 kGy.

Cherry. Irradiation at 1.0 kGy caused a significant increase in the darkness of 'Van' and redness of 'Lambert' sweet cherries and increased soluble solids in both cultivars (Eaton et al. 1970). Cherries irradiated up to 0.3 kGy tended to remain darker red that controls but were still marketable (Jessup 1990). The quality of 'Ron's Seedling', 'American Bing', and 'Lambert' sweet cherry drupes was not affected by doses of up to 1.0 kGy (Jessup et al. 1992).

Cucumber. Cucumbers tolerated dosages of 0.5 kGy (Balock et al. 1966).

Cranberry. Eaton et al. (1970) found no significant effect on the shelflife of 'McFarlin' cranberries when they were held for 122 hours at room temperature.

Grape. Irradiation at 1.0 kGy caused a significant decrease in the texture to 'Emperer' and 'Tokay' grapes (Maxie et al. 1964).

Grapefruit. 'Duncan' grapefruit had peel damage when treated at 1 kGy (Dennison et al. 1966). Hatton et al. (1982) irradiated early-, mid-, and late-season 'Marsh' and 'Ruby Red' grapefruit at doses of 0.15, 0.3, 0.6, and 0.9 kGy. In most cases, rind breakdown increased progressively with increased irradiation dosage, especially in mid- and late-season fruit. Irradiation dosages with 0.15 and 0.3 kGy were satisfactory because fruit were acceptable with only slight rind injury, but irradiation dosages of 0.6 and 0.9 kGy were unsatisfactory because of excessive rind breakdown. Lester & Wolfenbarger (1990) compared different irradiation doses and rates of a single dose on grapefruit peel injury response. They concluded that a lower dose-rate (0.25 kGy) should impart little damage to grapefruit peel tissue. There was no obvious visible damage to 'Marsh' grapefruit treated with 0.05 kGy followed by 5 days at 1.1C (von Windeguth & Gould 1990).

Lemon. Internal and external quality of 'Lisbon' lemons was decreased at doses up to 1.0 kGy (Jessup et al. 1992). Maxie et al. (1969) found that 'Eureka' lemons developed large cavities between segments after storage for 30 to 40 days at 15C following irradiation at 0.5 to 1.0 kGy. There were no noticeable quality changes in 'Eureka' lemons irradiated at 0.75 to 1.0 kGy and then stored at 7C for six weeks (Moy & Nagai 1985).

Lychee. Balock et al. (1966) found 'Brewster', 'Hak Ip', 'Hung Lai', and 'Kwai Mi' lychees to tolerate doses of 0.5 kGy. Jessup et al. (1992) concluded that although irradiation up to 1.0 kGy increased pericarp browning of 'Bengal' lychees, the effect was not of economic importance. McLauchlan et al. (1992) reported that irradiation at 0.75 kGy had no effect on the internal and external quality of 'Tai So' lychees.

Mango. The shelf life of 'Haden' mangos was adversely affected at 1.0 kGy while doses of 0.25 to 0.75 kGy did not affect shelf life (Akamine & Goo 1971). Balock et al. (1966) found 'Pirie' mangos not to be adversely affected at dosages up to 1.0 kGy while 'Haden' mangos tolerated a maximum of only 0.15 kGy without injury. Beyers et al. (1979) concluded that the nutritional value of 'Kent', 'Zill', 'Haden', and 'Peach' mangos was not affected by 0.75 kGy radiation. Irradiation at 0.75 kGy did not alter the internal composition of 'Kent' mangos (Blakesley et al. 1979). Decay of 'Tommy Atkins' mangos was 77% for fruit exposed to 0.75 kGy (Burditt et al. 1981). Irradiation caused dark, sunken areas in the surface of the skin of 'Keitt' mangos and the degree of injury was directly related to the irradiation dosage. The lowest dosage tested, 0.25 kGy, caused surface damage on 15% of the fruit (Burditt et al. 1981). Bustos et al. (1992) found no decrease in quality of 'Ataulfo', 'Kent', and 'Keitt' mangos at doses to 1.0 kGy. Hatton et al. (1961) found that the flavor was impaired when 'Irwin' mangos were treated above 0.1 kGy and 'Sensation' above 0.15 kGy. Mitchell et al. (1990) concluded that 0.6 kGy had no significant effect on the carotene levels of 'Kensington Pride' mangos. Manoto et al. (1992) found acceptable quality in 'Carabao' mangos treated at 0.1 to 0.25 kGy. Spalding & von Windeguth (1988) determined that a dose of ≥0.25 kGy should be avoided to avoid injury to 'Tommy Atkins' and 'Keitt' mangos. Thomas & Beyers (1979) reported that no significant change could be detected in nutritional value of 'Kent' and 'Zill' mangos after irradiation at 0.75 kGy. However, 'Harumanis' mangos tolerated 0.75 kGy with no significant injury (Vijaysegaran et al. 1992). Jessup et al. (1988) studied the combination of dipping 'Kensington' mangos in a benomyl solution (500 ppm) or in water at 52C for 5 min followed by irradiation at doses up to 1.0 kGy. Irradiation retarded skin color and increased skin wrinkling and skin bronzing with the effect being dose dependent. Significantly more skin bronzing and wrinkling occurred when mangos were treated with heated water and heated benomyl.

Nectarine. Irradiation at 0.3 to 1.0 kGy did not adversely affect the sensory or nutrient qualities of 'Fairlane' nectarines (Moy & Nagai 1985). 'Autumn Gold', 'Fairlande', 'Flamekist', 'Niagara Grand', 'Red Grand', 'Sam Grand', 'Summer Grand', and 'Sun Grand' nectarines tolerated doses between 0.5 to 0.75 kGy (Moy et al. 1992).

Orange. Oranges had peel injury when irradiated at 1.0 kGy (Dennison et al. 1966). The ascorbic acid content of oranges was not affected by doses between 0.025 and 0.3 kGy (Jessup et al. 1992). Kahan & Monselise (1965) found no difference in the internal and external appearance of 'Valencia' oranges following irradiation at 1.0 kGy and six weeks' storage at 25C. Taste panel ratings of aroma and flavor of juice from 'Washington navel' oranges irradiated at 1.0 kGy were distinctly less than ratings of control fruit (Maxie et al. 1969). The qualities of 'Valencia' and 'Navel' oranges irradiated at 0.75 to 1.0 kGy and then stored at 7C were retained for at least six weeks (Moy & Nagai 1985). Moy et al. (1992) found no damage to 'Valencia' oranges at doses of 0.5 to 0.75 kGy.

Passion fruit. The shelf life of yellow passion fruit was not affected by irradiation at 0.25 to 1.0 kGy (Akamine & Goo 1971).

Papaya. Akamine & Goo (1971) reported that 1.0 kGy did not adversely affect shelf life of papayas. 'Solo' papaya showed no damage when irradiated at doses between 0.25 to 1.0 kGy (Balock et al. 1966; Moy & Nagai 1985; Moy et al. 1992). The nutritional value of 'Hortus Gold' and 'Papino' papayas was not found to be affected by 0.75 kGy radiation (Beyers et al. 1979). Irradiation at 0.75 kGy did not alter the internal composition of 'Papino' papayas (Blakesley et al. 1979; Thomas & Beyers 1979). No damage was reported by Vijaysegaran et al. (1992) when 'Eksotika' mangos were treated at 0.3 kGy.

Peach. Moy & Nagai (1985) showed that 'Autumn Gem' peaches could be irradiated at 0.3 to 1.0 kGy without adverse effects on sensory and nutrient qualities. The quality of 'Fay Alberta' and 'O'Henry' peaches was retained after irradiation doses of 0.5 to 0.75 kGy (Moy et al. 1992).

Pepper. Mitchell et al. (1990) found 0.3 kGy to not alter the level of carotene in red pepper.

Plum. The sensory and nutrient qualities of 'Casselman' plums were not adversely affected by irradiation at 0.3 to 1.0 kGy (Moy & Nagai 1985). There was no decrease in the quality of 'Casselman', 'Friar', 'Kelsey', 'Laroda', and 'President' plums treated at doses of 0.5 to 0.75 kGy (Moy et al. 1992).

Sour sop. Irradiation of sour sop at 0.1 to 1.0 kGy caused physiological disturbance in that the fruit did not soften and the interior of the fruits was severely darkened (Akamine & Goo 1971).

Tomato. Abdel-Kader et al. (1968) found that 'Early Pak No. 7' tomatoes ripened normally after irradiation at 1.0 kGy. Tomato cultivars 'Anahu', 'Homestead 24', 'Rutgers', and seven unnamed cultivars tolerated doses of 0.25 to 1.0 kGy (Balock et al. 1966).

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Table 1. Relative tolerance of fresh fruits and vegetables to irradiation at doses ≤1.0 kGy.

Relative tolerance	Commodities
High	Apple, cherry, date, guava, longan, mango, muskmelon, nectarine, papaya, peach, rambutan, raspberry, strawberry, tamarillo, tomato
Moderate	Apricot, banana, cherimoya, fig, grapefruit, kumquat, loquat, lychee, orange, passion fruit, pear, pineapple, plum, tangelo, tangerine
Low	Avocado, broccoli, cauliflower, cucumber, grape, green bean, lemon, lime, leafy vegetables, olive, pepper, sapodilla, soursop, summer squash

Table 2. Response of fruits and vegetables to irradiation treatment with respect to damage.

Commodity	Dose (*kGy*)	Damage	Reference
Apple	0.05-0.3	No	Angerilli & Fitzgibbon (1990)
Apple	0.2-1.0	No	Olsen et al. (1989)
Avocado	0.03-0.5	Yes	Alkamine & Goo (1971)
Avocado	0.25	Yes	Balock et al. (1966)
Avocado	0.1	Yes	Jessup et al. (1992)
Banana	0.5	No	Balock et al. (1966)
Banana	0.5	No	Ferguson et al. (1966)
Banana	0.25-1.0	Yes	Thomas et al. (1971)
Blueberry	1.0	Yes	Eaton et al. (1970)
Blueberry	1.0	No	Miller et al. (1994)
Carambola	0.05-0.5	No	Gould & von Windeguth (1991)
Carambola	≥0.2	Yes	Vijaysegaran et al. (1992)
Cherry, sweet	1.0	Yes	Eaton et al. (1970)
Cherry, sweet	0.3	No	Jessup (1990)
Cherry, sweet	0.075-1.0	No	Jessup et al. (1992)
Cucumber	0.5	No	Balock et al. (1966)
Cranberry	0.5-0.79	No	Eaton et al. (1970)
Grape	1.0	Yes	Maxie et al. (1964)
Grapefruit	1.0	Yes	Dennison et al. (1966)
Grapefruit	0.15-0.3	No	Hatton et al. (1982)
Grapefruit	0.25	No	Lester & Wolfenbarger (1990)
Grapefruit*	0.05	No	von Windeguth & Gould (1990)
Lemon	0.075-1.0	Yes	Jessup et al. (1992)
Lemon	0.5-1.0	Yes	Maxie et al. (1969)
Lemon	0.75-1.0	No	Moy & Nagai (1985)
Lychee	0.5	No	Balock et al. (1966)
Lychee	0.075-1.0	No	Jessup et al. (1992)
Lychee	0.75	No	McLauchlan et al. (1992)
Mango	0.25-1.0	Yes	Akamine & Goo (1971)
Mango	0.15-1.0	Yes	Balock et al. (1966)
Mango	0.75	No	Beyers et al. (1979)
Mango	0.75	No	Blakesley et al. (1979)
Mango	0.25-0.75	Yes	Burditt et al. (1981)
Mango	1.0	No	Bustos et al. (1992)
Mango	0.1-1.0	Yes	Hatton et al. (1961)
Mango	0.6	No	Mitchell et al. (1990)
Mango	0.1-0.25	No	Manoto et al. (1992)
Mango	≥0.25	Yes	Spalding & von Windeguth (1988)

Commodity	Dose (*kGy*)	Damage	Reference
Mango	0.75	No	Thomas & Beyers (1979)
Mango	0.75	No	Vijaysegaran et al. (1992)
Mango*	1.0	Yes	Jessup et al. (1988)
Nectarine	0.3-1.0	No	Moy & Nagai (1985)
Nectarine	0.5-0.75	No	Moy et al. (1992)
Orange	1.0	Yes	Dennison et al. (1966)
Orange	0.025-0.3	No	Jessup et al. (1992)
Orange	1.0	No	Kahan & Monselise (1965)
Orange	1.0	Yes	Maxie et al. (1969)
Orange	0.75-1.0	No	Moy & Nagai (1985)
Orange	0.5-0.75	No	Moy et al. (1992)
Passion fruit	0.25-1.0	No	Akamine & Goo (1971)
Payaya	1.0	Yes	Akamine & Goo (1971)
Papaya	1.0	No	Balock et al. (1966)
Papaya	0.75	No	Beyers et al. (1979)
Papaya	0.75	No	Blakesley et al. (1979)
Papaya	0.25-1.0	No	Moy & Nagai (1985)
Papaya	0.5-0.75	No	Moy et al. (1992)
Papaya	0.75	No	Thomas & Beyers (1979)
Papaya	0.3	No	Vijaysegaran et al. (1992)
Peach	0.3-1.0	No	Moy & Nagai (1985)
Peach	0.5-0.75	No	Moy et al. (1992)
Pepper, red	0.3	No	Mitchell et al. (1990)
Plum	0.3-1.0	No	Moy & Nagai (1985)
Plum	0.5-0.75	No	Moy et al. (1992)
Sour sop	0.1-1.0	Yes	Akamine & Goo (1971)
Tomato	1.0	No	Abdel-Kader et al. (1968)
Tomato	0.25-1.0	No	Balock et al. (1966)

*Denotes combination treatment.

Table 3.

Table 1. Some potential applications and limitations of the use of ionizing energy in the processing of fresh fruits and vegetables

Commodities	Treatment objective	Estimated minimum dose required, kilograys	Estimated maximum dose tolerated, kilograys	Detrimental effects above maximum dose tolerated	Alternative treatments available
Potato, onion, garlic, carrot, table beet, radish, turnip, Jerusalem artichoke, sweet potato, yam, cassava, taro, ginger	Inhibition of growth (sprouting and rooting)	0.05-0.10	0.15	Decreased wound healing ability[a] Tissue discoloration Increased susceptibility to decay	Use of sprout inhibitors (e.g., maleic hydrazide and chloroisopropyl carbamate) Maintenance of optimum temperature and relative humidity
Asparagus	Inhibition of growth (elongation and curvature)	0.05-0.10	0.25	Tissue breakdown Increased susceptibility to decay	Vertical packing and maintenance of optimum temperature (36°F, 2°C) and relative humidity (95-98%) Use of elevated carbon dioxide atmospheres
Mushrooms	Inhibition of growth (cap opening and elongation) Reduced discoloration	0.06-0.50	1.0	Development of off-flavors	Prompt cooling and maintenance of optimum temperature (32°F, 0°C) and relative humidity (95-98%)
Artichoke, asparagus, broccoli, brussels sprouts, cabbage, cauliflower, lettuce, spinach, other leafy vegetables	Insect disinfestation (prevention of adult emergence)	0.15-0.30	0.25	Loss of green color Stem pitting of artichoke Tissue discoloration	Fumigation with hydrogen cyanide (can be detrimental to quality of most commodities in this group)
Snap beans, sweet corn, cucumber, eggplant, okra, green peas, bell peppers, summer squash	Insect disinfestation	0.15-0.30	0.50	Loss of green color Increased denting of sweet corn Tissue discoloration	Fumigation with methyl bromide (can be detrimental to quality)
Cantaloupe, honeydew melons, Persian melons, casaba melons, tomatoes	Insect disinfestation	0.15-0.30	1.00	Accelerated softening Abnormal ripening	Fumigation with methyl bromide (can be detrimental) Short vapor heat treatment
Apple, apricot, blueberry, cherry, fig, loquat, nectarine, peach, pear, persimmon, plum, pomegranate, raspberry, strawberry, tamarillo	Insect disinfestation	0.15-0.30 depending on the commodity	0.50-1.75	Accelerated softening Abnormal ripening	Fumigation with methyl bromide (can be detrimental) Cold treatments
	Control of postharvest molding	1.50-2.00	3.0		Use of postharvest fungicides
Avocado, grapefruit, grape, kiwifruit, kumquat, lemon, lime, olive, orange, tangelo, tangerine	Insect disinfestation	0.15-0.30	0.25-0.75 depending on the commodity	Accelerated softening Tissue discoloration Surface pitting	Cold treatments (can be detrimental)
Banana, mango, papaya, pineapple, plantain, guava, lychee, longan, rambutan, cherimoya, carambola, passion fruit, sapodilla	Insect disinfestation	0.15-0.30	0.50-1.50, depending on the commodity	Accelerated softening Uneven ripening Tissue discoloration	Hot water or vapor heat treatments Fumigation with methyl bromide (can be detrimental)
	Retardation of ripening	0.25-1.0			Temperature management Ethylene removal Controlled atmospheres

[a]This is a problem only for wounds that are made after processing. Prior wounds can be allowed to heal before processing.

Source: Anonymous. Ionizing energy in food processing and pest control: II. Applications. Council for Agricultural Sciences and Technology

Table 4.

Table 1. Comparison of maximum tolerable doses and minimum dose required for desired technical effects on selected fresh fruit and vegetables.

Commodity	Desired technical effect	Estimated max tolerable dose in Krad	Estimated min dose required in Krad	Phenomena limiting commercial application
Apples	Control of scald and brown core	100 - 150	No effect below 150	Cheaper, more effective alternatives, tissue softening
Apricots	Inhibition of brown rot	50	200	Tissue softening
Asparagus	Inhibition of growth	15	5 - 10	Economics, short season, small acreage
Avocados	Inhibition of ripening and rot	25 25	None applicable	Cheaper, more effective alternatives, browning and softening of tissues
Bananas	Inhibition of ripening	50	30-35	Cheaper, more effective alternatives
Boysenberries	Inhibition of gray mold	100	200	Tissue softening
Cantaloupes	Inhibition of ripening	200	No effect below 200	Cheaper, more effective alternatives
Lemons	Inhibition of penicillium rots	25	150-200	Severe injury to fruit at doses of 50 Krad or more, cheaper, more effective alternatives
Limes	Inhibition of penicillium rots	25	150-200	Pronounced off-flavors, cheaper, more effective alternatives
Mushrooms	Inhibition of stem growth and cap opening	100	200	Cheaper, more effective alternatives
Nectarines	Inhibition of brown rot	100	200	Tissue softening
Oranges	Inhibition of penicillium rots	200	200	Cheaper, more effective alternatives, no technical effect under commercial conditions
Papayas	Disinfestation of Hawaiian fruit fly	75-100	25	Economics, inadequate acreage
Peaches	Inhibition of brown rot	100	200	Tissue softening
Pears	Inhibition of ripening	100	250	Abnormal ripening; cheaper, more effective alternatives
Potatoes	Inhibition of sprouting	20	8-15	Cheaper, more effective alternatives
Raspberries	Inhibition of gray mold	100	200	Tissue softening
Strawberries	Inhibition of gray mold	200	200	Cheaper, equally effective alternatives
Table grapes	Inhibition of gray mold	25-50	1,000	Tissue softening, severe off-flavors, cheaper, more effective alternatives
Tomatoes	Inhibition of alternaria rot	100-150	300+	Abnormal ripening, tissue softening

Source: Maxie, E.C., N.F. Sommer and F.G. Mitchell. 1971. Infeasibility of irradiating fresh fruits and vegetables. HortScience 6:202-204.

Irradiation Effects on Quality of Horticultural Commodities

Roy E. McDonald

Introduction. In 1956, gama-radiation was proposed as a potential quarantine treatment for fruits. At that time, work was begun at the USDA Laboratory in Hawaii to determine the effects of gama-radiation on fruit flies infesting papayas and other tropical fruits. Much has been learned over the intervening years on this technology. Most of this work has dealt with insect mortality, yet some studies also have dealt with the effect on fruit quality and condition.

During any handling or treatment following harvest, horticultural commodities can be damaged. This is particularly true when commodities are subjected to some quarantine treatments required for disinfestation purposes. It is important that quarantine treatments such as irradiation are efficacious but do not adversely affect the commodity's quality, condition, and susceptibility to decay. If the quarantine treatment reduces the value of the commodity, then the treatment is not fully effective. In other words, any treatment that disinfests a commodity should have minimal deleterious effects on that commodity. Damage manifests itself as the loss of market quality attributes including shelf life, appearance, flavor, texture, aroma, and increased susceptibility to decay organisms.

Factors influencing response. Several factors influence the response of fresh fruits and vegetables to irradiation and include characteristics of individual commodities or irradiation procedures. Also, preharvest factors such as climatic conditions and cultural practices affect composition and quality of these commodities, which may influence their response to irradiation stress. Additionally, the manner in which radiation is administered can affect the response of commodities.

Most fresh fruits and vegetables will tolerate ionizing radiation at 0.25 kGy with minimal detrimental effects on quality. At doses between 0.25 and 1.0 kGy, some commodities can be damaged. Generally, non-fruit vegetables (e.g., lettuce) are much more sensitive to irradiation stress than are fruits (e.g., apples) and fruit-vegetables (e.g., tomatoes). The relative tolerance of fresh fruits and fruit-vegetables to ionizing radiation at doses below 1 kGy is presented in Table 1. Some fruits have a high relative tolerance to irradiation and only slight detrimental effects have been reported. Other fruits have a moderate relative tolerance to irradiation. There have been some inconsistencies among the research reports on these fruits and further evaluation is needed. A third group of fruits has a low relative tolerance to irradiation. Most published data on these fruits indicate significant detrimental effects, and further investigation is likely to be nonproductive. As noted earlier, the relative tolerance of individual commodities is influenced by many factors. Consequently, its position in this classification may vary according to production area, season, and postharvest handling procedures.

Irradiation effects on the quality and condition of fruits and vegetables have been assessed differently depending upon the evaluator. Opinions among researchers have varied widely as to the point at which commodity injury is important. Horticulturists, postharvest physiologists, and other plant scientists are generally far more critical of injury effects than scientists not accustomed to studying living commodities. As a consequence, large differences are found in reports on quality and condition due to irradiation. For example, I have peer reviewed reports where an individual has considered a commodity still marketable if not more than half the surface area was covered with decay. I don't believe that the average consumer would go into a store and consider buying a tomato if the top one/fourth was decayed. However, according to the inspection protocol that this particular scientist used, he would have bought that particular tomato.

Effects on commodities. Radiation can affect fresh fruits and vegetables in several ways. The effects are manifested in the processes of ripening and softening, the development of aromas and flavors, disease susceptibility, and death or browning of tissues.

A number of studies with irradiation have been considered for the purpose of insect disinfestation of fresh fruits and vegetables. A large number of these studies dealt only with insect mortality. The studies referred to in Table 2 considered the resulting market quality of the product as a consequence of the disinfestation treatment.

Balock et al., (1966) found ten Hawaiian-grown cultivars of avocados to be extremely sensitive to 0.25 kGy, and Jessup et al. (1992) found damage at 0.1 kGy. 'Williams' bananas suffered skin russeting at 0.5 kGy but no impairment of flavor (Balock et al. 1966). Carambola phytotoxicity tests at doses ranging from 0.05 to 1.5 kGy indicated that no observable damage occurred at levels between 0.05 and 0.5 kGy (Gould & von Windeguth 1991). However, Vijaysegaran et al. (1992) found carambolas to be damaged at doses in excess of 0.2 kGy. Cherries irradiated up to 0.3 kGy tended to remain darker red that controls but were still marketable (Jessup 1990). Cucumbers tolerated dosages of 0.5 kGy (Balock et al. 1966). 'Duncan' grapefruit had peel damage when treated at 1 kGy (Dennison et al. 1966). Hatton et al. (1982) irradiated early-, mid-, and late-season 'Marsh' and 'Ruby Red' grapefruit at doses of 0.15, 0.3, 0.6, and 0.9 kGy. In most cases, rind breakdown increased progressively with increased irradiation dosage, especially in mid- and late-season fruit. Irradiation dosages with 0.15 and 0.3 kGy were satisfactory because fruit were acceptable with only slight rind injury but, irradiation dosages of 0.6 and 0.9 kGy were unsatisfactory because of excessive rind breakdown. Lester and Wolfenbarger (1990) compared different irradiation doses and rates of a single dose on grapefruit peel injury response. They concluded that a lower dose-rate (0.25 kGy) should impart little damage to grapefruit peel tissue. 'Marsh' grapefruit treated with 0.05 kGy followed by 5 days at 1.1C indicated no obvious visible damage to the fruit (von Windeguth & Gould 1990). Internal and external quality of lemons was decreased at doses up to 1.0 kGy (Jessup et al. 1992). Balock et al. (1966) found four cultivars of lychee to tolerate doses of 0.5 kGy. Balock et al. (1966) found 'Pirie' mangos not to be adversely affected at dosages up to 1.0 kGy while 'Haden' mangos tolerated a maximum of only 0.15 kGy without injury. Decay of 'Tommy Atkins' mangos was 77% for fruit exposed to 0.75 kGy (Burditt et al 1981). Irradiation caused dark, sunken areas in the surface of the skin of 'Keitt' mangos and the degree of injury was directly related to the irradiation dosage. The lowest dosage tested, 0.25 kGy, caused surface damage on 15% of the fruit (Burditt et al. 1981). Bustos et al. (1992) found no decrease in quality of mangos at doses to 1.0 kGy. Mitchell et al. (1990) concluded that 0.6 kGy had no significant effect on the carotene levels of 'Kensington Pride' mangos. Manoto et al. (1992) found acceptable quality in 'Carabao' mangos treated at 0.1 to 0.25 kGy. Spalding and von Windeguth (1988) determined that a dose of ≥0.25 kGy should be avoided to avoid injury to 'Tommy Atkins' and 'Keitt' mangos. However, 'Harumanis' mangos tolerated 0.75 kGy with no significant injury (Vijaysegaran et al. 1992). Jessup et al. (1988) studied the combination of dipping 'Kensington' mangos in a benomyl solution (500 ppm) or in water at 52C for 5 min followed by irradiation at doses up to 1.0 kGy. Irradiation retarded skin color and increased skin wrinkling and skin bronzing with the effect being dose dependent. Significantly more skin bronzing and wrinkling occurred when mangos were treated with heated water and heated benomyl. Nectarines tolerated doses between 0.5 to 0.75 kGy (Moy et al. 1992). Oranges had peel injury when irradiated at 1.0 kGy (Dennison et al. 1966). The ascorbic acid content of oranges was not affected by doses between 0.025 and 0.3 kGy (Jessup et al. 1992). However, Moy et al. (1992) found no damage at doses of 0.5 to 0.75 kGy. 'Solo' papaya showed no damage when treated at 1.0 kGy (Balock et al. 1966), at 0.5 to 0.75 kGy (Moy et al. 1992), or at 0.3 kGy (Vijaysegaran et al. 1992). The quality of peaches was retained after irradiation doses of 0.5 to 0.75 kGy (Moy et al. 1992). Mitchell et al. (1990) found 0.3 kGy to not alter the level of carotene in red pepper. There was no decrease in the quality of plums treated at doses of 0.5 to 0.75 kGy (Moy et al. 1992). Ten tomato cultivars tolerated doses of 0.25 to 1.0 kGy (Balock et al. 1966).

Future research. Several areas should be considered for future research on the effects of irradiation on the quality and condition of horticultural commodities. Pre- or postharvest treatments which would reduce damage need to be developed. Improved horticultural practices such as irrigation, hormonal sprays, fertilization, and increasing calcium uptake may increase resistance to the stress of some treatments. Other factors include: maturity of the commodity at harvest, time between harvest and treatment, and post-treatment storage conditions.

Another endeavor would be to discover the physiological basis of the conditioning phenomenon, a pretreatment process which has been shown to reduce damage from heat and cold treatments. Conditioning treatments could alleviate some of the damage from irradiation exposure. An example would be determining the changes in membrane lipids as a result of conditioning which play a role in conferring tolerance to certain physical quarantine treatments.

There is also a need for determining the physiological and biochemical basis of damage resulting from irradiation treatments. An example would be describing and documenting cell wall and enzymatic changes in fruit tissues related to irradiation treatment injury. This work could provide information that would allow reduced commodity damage.

Another area is the development of objective methods for measuring damage from treatments in order to provide uniformity in assessing quality and damage and to also provide quantifiable information which can be related to biochemical indices. Examples include development of methods for measuring chlorophyll fluorescence, instrumental methods for measuring texture, and other physical-chemical methods which correlate to sensory changes caused by stressful irradiation treatments.

Lastly, there is need to relate biochemical indices to damage incurred as a result of radiation. These indices could be used to indicate the thresholds of damage or to predict the potential for damage. Development of this type information will permit greater flexibility in the development of quarantine irradiation treatments.

Summary. Some of the irradiation treatments have no deleterious effects on the condition and quality of some commodities and cultivars. However, injury can occur at times with approved treatments under commercial conditions. It is important that treatments developed under laboratory conditions be feasible in a commercial setting. The treatment protocol must tolerate not only the variability in commodity condition, but also treatment variations which occur under commercial conditions without leading to commodity damage or insect survival.

Table 1. Relative tolerance of fresh fruits and vegetables to irradiation at doses ≤1.0 kGy.

Relative tolerance	Commodities
High	Apple, cherry, date, guava, longan, mango, muskmelon, nectarine, papaya, peach, rambutan, raspberry, strawberry, tamarillo, tomato
Moderate	Apricot, banana, cherimoya, fig, grapefruit, kumquat, loquat, lychee, orange, passion fruit, pear, pineapple, plum, tangelo, tangerine
Low	Avocado, broccoli, cauliflower, cucumber, grape, green bean, lemon, lime, leafy vegetables, olive, pepper, sapodilla, soursop, summer squash

Table 2. Response of fruits and vegetables to quarantine irradiation treatment with respect to damage.

Commodity	Dose (*kGy*)	Damage	Reference
Avocado	0.25	Yes	Balock et al. (1966)
Avocado	0.1	Yes	Jessup et al. (1992)
Banana	0.5	No	Balock et al. (1966)
Carambola	0.05-0.5	No	Gould & von Windeguth (1991)
Carambola	≥0.2	Yes	Vijaysegaran et al. (1992)
Cherry, sweet	0.3	No	Jessup (1990)
Cucumber	0.5	No	Balock et al. (1966)
Grapefruit	1.0	Yes	Dennison et al. (1966)
Grapefruit	0.15-0.3	No	Hatton et al. (1982)
Grapefruit	0.25	No	Lester & Wolfenbarger (1990)
Grapefruit*	0.05	No	von Windeguth & Gould (1990)
Lemon	1.0	Yes	Jessup et al. (1992)
Lychee	0.5	No	Balock et al. (1966)
Mango	0.15-1.0	Yes	Balock et al. (1966)
Mango	0.25-0.75	Yes	Burditt et al. (1981)
Mango	1.0	No	Bustos et al. (1992)
Mango	0.6	No	Mitchell et al. (1990)
Mango	0.1-0.25	No	Manoto et al. (1992)
Mango	≥0.25	Yes	Spalding & von Windeguth (1988)
Mango	0.75	No	Vijaysegaran et al. (1992)
Mango*	1.0	Yes	Jessup et al. (1988)
Nectarine	0.5-0.75	No	Moy et al. (1992)
Orange	1.0	Yes	Dennison et al. (1966)
Orange	0.025-0.3	No	Jessup et al. (1992)
Orange	0.5-0.75	No	Moy et al. (1992)
Papaya	1.0	No	Balock et al. (1966)
Papaya	0.5-0.75	No	Moy et al. (1992)
Papaya	0.3	No	Vijaysegaran et al. (1992)
Peach	0.5-0.75	No	Moy et al. (1992)
Pepper, red	0.3	No	Mitchell et al. (1990)
Plum	0.5-0.75	No	Moy et al. (1992)
Tomato	0.25-1.0	No	Balock et al. (1966)

*Denotes combination treatment.

QUESTIONS, ANSWERS, COMMENTS AND DISCUSSION ON DR. ROY McDONALD'S PRESENTATION

Comment: We have learning experiences in continuing research on mangos in Canada, for shelf life extension. People come to the conclusion that with mangos if you don't irradiate them within 24 to 30 hours after harvest, you might have accelerated ripening, rather than extending shelf life. You can't keep it too long, or you might find a softening effect.

Speaker: Yes, that's actually true, of course, based on the generalization about prior condition for irradiation response of fruit and vegetables.

Question: I have a question in the literature you reviewed. Did you come across work that would indicate irradiation's effects on water loss during subsequent storage and also what are the consequences of condensational products as they're irradiated? Does it mitigate problems? If your are you taking them out of cold storage, for example, and putting them in an irradiator, will they have liquid water condensed on them?

Speaker: I did not specifically review the literature to that effect. I think that if there is a problem, I have a feeling you have the answer.

Questioner: No, I have no idea.

Speaker: To answer your question quickly, I have no information on that subject.

Question: Would it be sensible to say that irradiation would promote water loss, subsequent to treatment?

Speaker: Yes, it is possible, because of the possibility of increased respiration. It could happen, but I don't know of anyone who has done this work. I know in our lab, we routinely look at water loss e.g., in blueberries, and we did not see any water loss due to irradiation. We always weigh the commodity when we bring it in, before we treat it and all the way through, to see if there's anything like that.

Comment: I think we also have to be very, very careful when we are dealing with effects due to irradiation and not due to closed source irradiators of small types. In particular gamma cell types. They are not recommended for irradiation.

Comment: Yes, in a survey like this one; you have to be careful. I am not criticizing, but generally speaking, you have to be careful of what is pointed out as damage. I am thinking back about a dozen years ago to a study where observation of cold damage was reported, and it turned out to be some minor burn on the outer surface of the fruit which was not cold damage. For example, the Keitt mangos mentioned earlier this afternoon. In 1986 an irradiated mango market trial was done in Florida over a five week period, and we at ISOMEDIX had applied a dose range between 0.5 and 1 kGy to these mangos for excellent shelf life extension through ripening maturation and quality as excellent, there was no problem.

Speaker: Your point is well taken. In fact, when I read a lot of these papers and what I see is this. In materials and methods, it talks about how they set up the fruits for disinfestation, how they irradiate or heat treat ,or whatever treatment that was done, and they make no mention, whatsoever, of how they obtained the fruit. There was no mention of and quality evaluation whatsoever. You see one line often, and this is not just in irradiation, I am talking about any quarantine treatment, you see one line in the conclusion which says, there was no damage noticed in the fruit. That's it. And I think probably the literature errs more in that direction than perhaps in the direction that you're talking about, because I think that there is no conscious, effort to get fruit quality data. I'm talking about all quarantine treatments, not just irradiation.

Comment: Going back to that earlier question on irradiation in the presence of water or condensation, it isn't necessary in an industrial irradiator to have any condensation. You can control temperature within one or two degrees Fahrenheit, if that is necessary. We can maintain it.

[illegible] the translation [illegible]

[illegible] because of the possibility of increased [illegible] who has done the work. [illegible] and would not use any metal because [illegible] bring it in [illegible] anything [illegible]

[illegible] we also have to be very, very careful when we are [illegible] close counts [illegible] of small types [illegible] recommended for [illegible]

[illegible] like this one you have to be careful [illegible] more careful of what is pointed [illegible] study of the observation of cold damage [illegible] the outer surface [illegible] the [illegible] over a [illegible] and [illegible] to these [illegible]

NEW METHODS FOR DISTINGUISHING IRRADIATED VERSUS IMMATURE NON-IRRADIATED CARIBBEAN FRUIT FLIES: DEVELOPMENT OF OVARIAN STATUS AND STERILITY ASSAYS

by

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New Methods for Distinguishing Irradiated versus Immature Non-Irradiated Caribbean Fruit Flies: Development of Ovarian Status and Sterility Assays

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We propose to develop new field-applicable methods for assessing the reproductive status and sterility of females of the Caribbean fruit fly, *Anastrepha suspensa*, as needed during implementation of the Sterile Insect Technique.

These methods take advantage of recently discovered differences between the ovaries of sterile, irradiated and non-irradiated *A. suspensa*. The outward, gross morphological appearance of the ovaries of irradiated and young non-irradiated flies is similar; however, we have found that the cells that normally produce the major yolk protein of the eggs are destroyed in irradiated flies. We propose to develop tests that differentiate non-irradiated from irradiated females by the presence or absence of ovarian yolk proteins.

Antibodies to ovarian yolk protein can be used to develop an ELISA (Enzyme Linked Immunosorbent Assay) and ELISA-based rapid tests to differentiate sterile and feral *A. suspensa*. Monospecific, polyclonal antisera to the major ovarian yolk protein in *A. suspensa* (Handler and Shirk, 1988) is available and is an immediate candidate for development into an assay system.

The similarity of ovary development and sterilizing irradiation schedules of *Anastrepha suspensa*, *Ceratitis capitata* (Mediterranean fruit fly) and *Anastrepha ludens* (Mexican fruit fly) suggests that diagnostic tools like those developed for *A. suspensa* could be developed for other tephritid flies.

Collaborators for Assay Development:
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TECHNICAL AND ECONOMIC ASPECTS OF GAMMA AND ELECTRON IRRADIATORS FOR GRAIN AND OTHER COMMODITIES

by

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Technical and Economic Aspects of Gamma and Electron Irradiators for Grain and Other Commodities

Dr. Joseph Borsa
Atomic Energy of Canada Limited

Thank you. It's a pleasure to be here today, and I want to thank Jennifer Sharp, Ken Vick and Ralph Ross for inviting me and giving me the opportunity to participate in this workshop.

I want to talk technically about irradiation disinfestation of grain. Hopefully, some of what I have to say will also be applicable to other commodities, since this is fairly general stuff. To begin, as you are no doubt aware, grain is a massively traded commodity and infestation problems within grain are very real. In this respect Canadian grain is no exception. Since grain is a massively traded commodity, loss of methyl bromide will have a severe negative effect on the free movement of grain in international trade. Irradiation seems particularly appropriate for disinfestation of grain. In this talk, therefore, I want to consider technical and cost aspects of grain irradiation, for both E-beam and gamma irradiators.

Let us consider briefly what are the factors which determine the suitability of irradiation as a means of disinfestation treatment. The critical ones are shown here(Figure 1). First is technical effectiveness. Does it produce the desired technical effect and, a second aspect of this, can any deleterious side effects be kept to an acceptable level? The second main category of determinants is cost. The processing cost per unit must be affordable and competitive. Finally, the process must be practical and convenient to use.

Let us briefly review what the source options are for radiation processing of grain. (Figure 2) Two main categories of sources are available for powering irradiators. These are radionuclide sources, here on the left, giving off gamma rays, and machine sources, on the right, which convert electricity into radiation. Machine generated radiation could be either high energy electrons, or the electrons could be converted into x-rays. The critical difference between the two source types is the dependence on radionuclide (cobalt-60) for the gamma ray case, while for electrons or x-rays electricity is converted into ionizing energy. These two main categories of sources each have some characteristics which are advantageous, and others which are disadvantageous, with respect to each other. The next two figures list the advantages and disadvantages of each kind of source.

For radioisotopes (Figure 3) the advantages are, first and foremost, its' simplicity and reliability. Gamma rays have excellent penetration characteristics. Low power (small processing capacity) is relatively cheap, and cobalt-60 facilities are easily incremented, meaning that you can start at whatever size you need, and then you can grow as the requirement grows. Gamma rays from cobalt-60 are the dominant power source for commodity irradiators worldwide. There is a very large experience base with cobalt-60, and the supplier of cobalt- 60 has a very well proven track record. Cobalt metal is very stable so there is no problem with any dissemination to the environment, and so on.

The disadvantages of this mode of power are several fold. It can't be turned off, and it is isotropic, which means that it gives off energy in all directions, which has unfavorable implications for efficiency. There is a perceived waste disposal problem, at least in some quarters. There is a potentially limited availability of the source material. The linear power:cost relationship means that high power is relatively expensive. In the case of cesium-137, the cesium salt is soluble, which makes it unsuitable as a source in many applications.

For machine sources **(Figure 4)** the advantages include controllable power and energy levels, along with the possibility of very, very high dose rates. The capability of switching between electrons and x-rays provides extra flexibility. Machine sources are directional, which permits more efficient utilization of the source energy. Machine sources have an on/off feature. There is no perceived waste disposal problem. Throughput and cost are non-linearly related and, in particular, as things scale up, the cost lags very significantly behind the scale-up of power. In other words high power is cheap with E-beam sources. Finally, of course, there are multiple suppliers, which gives you the advantages of competition.

The disadvantages of the machine sources include their high-tech nature, meaning that they require more maintenance than low tech radionuclide sources. The high power and high energy machines are relatively new, with a limited experience base in their operation. However, this is increasing quickly,and steadily. At low power levels machine sources are relatively expensive. In addition, it is not easy to increment machine sources. You have to buy a complete machine in whatever size it comes..... you can't buy a fraction of a machine, if you only have need of a fraction of a load. Electrons, of course, have limited penetration ability and conversion to x-rays is inefficient, generally being less than ten per cent. Finally, because machine sources convert electricity to ionizing energy, their operation is sensitive to the cost of electricity.

Let us now consider the technical effectiveness of these types of radiation sources, for disinfestation. We need to be sure that insects are effectively prevented from reproducing and that the end-use qualities of the grain are not harmed. Of course, we need to do this for both gamma rays and high energy electrons.

Let us consider first the effects of irradiation on insect reproduction (**Figure 5**). Speaking to this group, I hardly need to spend any time on this at all, as you have heard several excellent presentations yesterday relating to this topic. Indeed, speaking here on this topic is something like carrying coal to Newcastle. In any event, in general for insect disinfestation of cereal grains, ICGFI recommends a dose of 0.50 kGy. A dose lower than 0.50 kGy can be used for those situations where only certain sensitive species are present. Notice the reference to some Russian data. I include this because I'm not sure how available this data is to everybody at large. I apologize to those early pioneers, several of which are present here today, who have contributed to this area,but which have not been included in this slide. At the irradiator at Odessa, a dose of 0.2 kGy is used for grain disinfestation. In 1987 Chuaqui-Offermanns in our group did a literature review on the radiation sensitivities of insect pests found around the globe. The general conclusion from that review was that a dose of 0.25 kGy effectively controls most pests likely to be found in infested wheat.

One question that immediately arises in the comparison of these two source types, is whether they are equally effective. This question is important because of differences in the instantaneous dose-rates between electrons and gamma rays. Yesterday, in his presentation, Dr. Burditt referred to some of his earlier work where at a 200-fold difference in dose-rate he found a very important dose-rate effect. Well, the difference in dose-rates between machine sources and gamma sources can be much greater than the range over which Dr. Burditt did his studies. Indeed the differences in dose-rates between machines and radionuclide sources can be in the order of a million-fold. This is a huge dose-rate difference, so it is important to compare their effectiveness for insect inactivation. I will present two different ways of examining this question. The first (**Figure 6**) is to examine the effects of the two types of radiation on insects. The Russians did some direct comparison work, using *Tribolium confusum* and three other species of insect as their test system. In the cited references the mortality curves of gamma and E-beam treated insects were the same, indicating that the two types of radiation treatment were equivalent. Similarly, in the same review of the literature by Dr. Chuaqui-Offermanns that I referred to earlier, all the available data indicated that there was no difference between gammas and electrons. Thus, the available data based on insect studies indicate that gamma rays and electrons are equivalent in terms of insect disinfestation, in spite of the vastly higher dose-rate associated with electron treatment.

Another way of looking at this is to compare some other biological effects of these two very different dose-rates, using appropriate biological systems. We examined microbial inactivation with gammas and with electrons. Using various indicator organisms we determined the inactivation efficiency of the two types of irradiation, both in liquid culture and in dry film. The results for *Bacillus pumilus* are shown in the next two slides, for irradiation in liquid culture **(Figure 7)** and dried films **(Figure 8)**, respectively. Examination of the data reveals no significant differences in inactivation efficiency between gamma ray and electron irradiation(at either 40 or 200 usec pulse length), in either culture condition. The data for a different organism, *Bacillus stearothermophilus,* are shown in the next set of two slides **(Figures 9 and 10)**. Again the experimental evidence indicates that the two types of radiation are equivalent.

Thus, the available evidence from both the insect studies and the microbiological studies indicates that, in spite of the great difference in dose-rate associated with gamma ray as compared to electron beam treatment, the biological effectiveness of the two types of ionizing energy is the same.

Let us consider the end use quality of the irradiated grain **(Figure 11)**. Working with collaborating cereal scientists at the University of Manitoba, we examined the effects of these two types of radiation treatment on the bread making quality of two of our most important cultivars of wheat, Neepawa and HY320. The experimental design included ten doses, between 0 and 5 kGy, at two different moisture levels, and two different storage times. The irradiated grain was analyzed for milling properties, flour properties, baking properties, and for some biochemical characteristics, including electrophoretic behavior of protein fractions. Our data **(Figure 12)** showed that there was no effect of the radiation treatment on the milling characteristics of the grain, and there were no significant effects on flour properties. A slight increase in starch damage, evident at the highest dose levels, was the same for both types of radiation. There were no significant effects on baking properties for less than 1 kGy, and there were no effects on the SDS-PAGE electrophoretic patterns, with both reduced and unreduced samples. So, in conclusion, one can say that, at doses appropriate for disinfestation, the end use quality of the grain was not deleteriously affected.

The conclusions regarding the technical effectiveness of irradiation as a disinfestation treatment for grain are summarized in **Figure 13**. First, irradiation can be used successfully to disinfest grain commodities, with both gamma and e-beam irradiation being equally effective. Both inhibit insect reproduction at equivalent rates and both have similar biological effects on microbial organisms. Both types are without significant deleterious effect on end use characteristics on wheat and flour at the appropriate doses. Thus, from the technical perspective, irradiation is an effective method for insect disinfestation in grain.

As indicated earlier, technical effectiveness is only one of the categories of determinants of whether or not a particular technology is suitable for this application. Without a doubt the cost of processing is one of the most important and critical non-technical determinants. I want to examine the cost of radiation processing to put it into perspective. To begin, in analyzing the cost of radiation processing, think of what kind of problem you've got. There are probably 30 or 40 variables impacting on the cost of processing grain. How do you get a good grasp on a function which involves 30 or 40 variables? Thirty or 40 variables is a huge number of variables, and the embracing function is very complex. I have used a particular approach which allows a systematic analysis of the cost function, and I will share this with you. This approach (**Figure 14**) is based on evaluating the cost function for a reference case, and then to carry out a sensitivity analysis to explore the cost space around the reference case condition. First I will describe our methodology, and then we'll actually work our way through two cases.

In the approach we followed, the first thing to do is to identify all the variables which impact on the cost of processing a particular commodity. Then, you link these variables together into a cost model. Of course, this can most conveniently be done by means of a computer spreadsheet. Next, a reference case scenario is defined by assigning reasonable values to each of the cost variables. The reference case values should realistically reflect the conditions relevant to the particular application being analyzed. A processing cost is then calculated for the reference case. This provides processing cost information, but only for the particular conditions represented by the reference case. Any real industrial situation will certainly differ from the reference case in the values appropriate for one or more of the cost variables. A sensitivity analysis is then carried out to define the behavior of the cost function in the region around the reference case operating point.

This analysis permits one to identify those variables which are most important in determining the behavior of the cost function. Such information allows one to optimize the operating conditions for maximum economic benefit.

That describes the methodology for the cost analyses, and I want to go now to a couple of examples. **Figure 15** shows the variables included in the cost model for electron beam processing. The model is specified by both financial and physical variables, the latter are required because physical optimization is essential for economic optimization. The reference case values for the most important variables are shown in **Figure 16**. The processing cost for the given reference case is $0.55 per tonne.

Let us now proceed with a sensitivity analysis for this application. To do this I will change one variable at a time, keeping the rest of the variables constant at the reference case value, and calculate the processing cost as a function of the variable under consideration. I won't go through the 25 or 30 variables incorporated in the cost model, but I will show you the results for perhaps a half dozen of them, and I will then summarize the conclusions for you.

Figure 17 shows the processing cost as a function of the facility utilization factor. For the reference case condition this was arbitrarily set to 100%, to provide an estimate of the best possible processing cost theoretically attainable. The data on this figure shows that as the facility utilization factor drops below 100%, the cost of processing increases. Inspection shows that the curve becomes steeper and steeper as the facility utilization factor becomes smaller and smaller. Thus, it is obvious that for most economical operation the facility should be utilized as fully as possible. This same functional relationship is shown in terms of the annual throughput of treated grain, in **Figure 18**. The different curves on this graph represent different configurations of machine size (50 or 30 kW) and number of shifts per day (1, 2, or 3). The results show that processing cost per tonne is inversely related to annual throughput, and that costs are lowest, at a given throughput, with that configuration which most fully utilizes the available capacity of the facility.

What effect would changing the dose have on the cost? The reference case is based on 0.3 kGy, but what will be the cost if some other dose is chosen? This is shown in **Figure 19**, where the processing cost is given as a function of dose. The reference case position is indicated by the arrow. In this case the cost is linearly related to dose, as indicated by the straight line form of the cost curve. Thus, if all the other variables do not change, then the cost is directly proportional to dose. Obviously, for maximum economic effectiveness, the minimum dose required to assure the desired technical effect should be used.

Radiation processing is a capital intensive activity. The processing cost of grain as a function of capital cost of the facility is shown in **Figure 20**. The reference case is shown by the arrow. The curve defines the processing cost for capital costs ranging from 2 $M to 9 $M. For capital intensive enterprises the cost of capital is very important. The processing cost as a function of interest rate is shown in **Figure 21**. This shows that the processing cost is linearly related to the interest rate used to finance the capital cost of the facility.

In the case of electron beam irradiation, electricity is being converted to ionizing energy. This makes the cost of processing dependent on the price of electricity. **Figure 22** shows that the processing cost is linearly related to the price of electricity

A very important consideration in the use of any type of irradiator is how much of the ionizing energy that is emitted, is usefully absorbed. This is specified by the beam utilization efficiency. Clearly it cannot be more than 100%, and generally it will be considerably below that. The reference case is based on a beam utilization efficiency of 55%, which should be attainable for grain in an e-beam facility. For other values of the efficiency, the processing cost is shown in **Figure 23**. In this case there is an inverse relationship between processing cost and beam utilization efficiency. Clearly it is desirable to keep the beam utilization efficiency as high as possible, for most economical operation.

Figure 24 summarizes the sensitivity analyses for all the variables, including several of the ones which we have not examined individually. In this graph, the slope of the cost curve at the reference case value for each variable is plotted in bar graph form. In effect the the slopes represent the partial derivatives for the cost function, with respect to each of the variables. These are directly derived from the sensitivity curves shown above. The bars represent the ratio of the relative change in processing cost to the relative change in the variable under consideration. The values represented by the bars can be directly interpreted as the percent change in processing cost resulting from each percent change in the variable being examined. For example, the ratio for equipment capital cost is seen, on the graph, to be approximately 0.45. This means that for each percent change in the capital cost of the equipment, the processing cost will change by 0.45 percent. Note that the ratio can be either positive or negative. Positive ratios mean that the changes of both cost and the specific variable are in the same direction, i.e. an increase, or decrease, in one will be associated with an increase, or decrease, in the other. A negative ratio means that the changes of cost and variable are in opposite directions, i.e. an increase in the variable will be associated with a decrease in the processing cost, and vice versa.

The format of this graph immediately allows one to identify which factors are the important ones for optimizing the running of the facility. The important ones are those which have the biggest bars on the graph! The little bars indicate that the cost is only weakly dependent on the variable represented by that bar. This is important in optimization of the operating conditions to yield maximum economic benefit. It is important to ensure that those variables which influence processing cost the most are the most carefully optimized.

Let us now do the equivalent analysis for gamma facility operating costs. The variables which impact on the operating costs of gamma facilities, along with their reference case values, are listed in **Figure 25**. In this case the reference case operating cost is $1.23 per tonne. Note that this is for a facility designed to treat 1000 kilometric tonnes per year, at full capacity.

To begin the sensitivity analysis for this facility let us proceed with **Figure 26**, which shows the processing cost as a function of annual throughput for the facility. As seen previously, with the e-beam facility, there is an inverse relationship between processing cost and annual throughput. In addition, this graph illustrates the beneficial effect of matching facility capacity to throughput requirements, which is feasible with radionuclide powered facilities. The upper curve shows the processing cost for the case where the indicated annual throughput is treated by a facility designed for 1000 kmt per year. In effect this curve shows the effect of varying facility utilization factor. The lower curve demonstrates the operating cost which would result if the facility was designed to exactly match the indicated annual throughput. The savings associated with size optimization are readily evident, with there being a factor of 2 or more in favor of the optimized facility at lower annual throughputs (<200,000 mt per year).

To continue with the sensitivity analysis, **Figure 27** shows the processing cost as a function of dose. As was the case with e-beam processing, the relationship between these two variables is a linear one. **Figure 28** shows the processing cost as a function of efficiency (percentage of ionizing energy usefully absorbed). The graph shows that there is an inverse relationship between these two variables, as was seen also for the e-beam facility.

The price of cobalt-60 is obviously an important determinant of the processing cost, and this is shown in **Figure 29**. The relationship is linear, as can be seen by inspection of the graph. The influence of capital cost of the equipment, the interest rate used to finance the capital cost, the amortization time and the number of operating days per year are shown in **Figures 30, 31, 32, and 33,** respectively.

A summary of the sensitivity analyses for the gamma irradiation facility is shown in **Figure 34**. The interpretation of the bars on this graph is the same as that for the corresponding graph described above for the e-beam case. Again the important factors are the ones that have the big bars on the graph. This type of graph facilitates optimization of the operating conditions for the facility to yield maximum economic benefits.

In summary, (**Figure 35**) irradiation between 0.2 and 0.5 kGy appears to be an efficacious treatment for insect disinfestation in grains and other commodities. At doses that are appropriate for disinfestation, there is no significant deleterious effect on end use properties of wheat and flour. For commodities other than grain, the technical effectiveness must be evaluated on a case by case basis. The cost for treatment, in terms of dollars per unit of throughput, appears to be very reasonable at annual throughputs common to commercial practice. Careful analysis of costs is necessary to identify the cost variables which most affect a given facility and to optimize the cost effectiveness of the facility.
Thank you.

Question: Joe, if you put throughputs the same for electrons and gamma, take a maximum gamma case and the same throughputs for the electron beam, how does the cost per tonne compare?
Response: The cost curves for the two facilities cross-over at some annual throughput. The cross-over point depends on the specifics of the two facilities. Below the cross-over point the gamma facility is cheaper, while at higher throughputs the e-beam is cheaper. In general, machine sources are favored by large throughputs, while gamma facilities come out ahead at lower throughputs. In this respect the two source types are complimentary.

Question: Is it correct to say that it is difficult to estimate the maximum/minimum ratio on E-beam?
Response: No, that's not difficult.

Question: What's the usual ratio?
Response: If one looks at the ratio under the conditions that this beam analysis was done, meaning isodose, the ratio is 1.4:1. The isodose condition is also the thickness which would give you maximum efficiency.

Dr. Burditt: Did you include in here replenishing the cobalt supply?
Response: Yes, that's in the cost model.

Burditt: .....and depreciation on the equipment?
Response: Yes, that is in the model.

Paisan: Joe, the costs that you presented, are they in Canadian or US dollars?
Response: These are US dollars.

Figure 1

Determinants of suitability of irradiation for disinfestation treatment

- **Technical effectiveness**
  - Does it produce the desired technical effect?
  - Can any deleterious side effects be kept at an acceptable level?
- **Cost**
  - Processing cost per unit of product must be affordable and competitive
- **Convenience and practicality**

Figure 2

Radiation Fields for Radiation Processing:

The radiation source is the heart of an irradiation facility

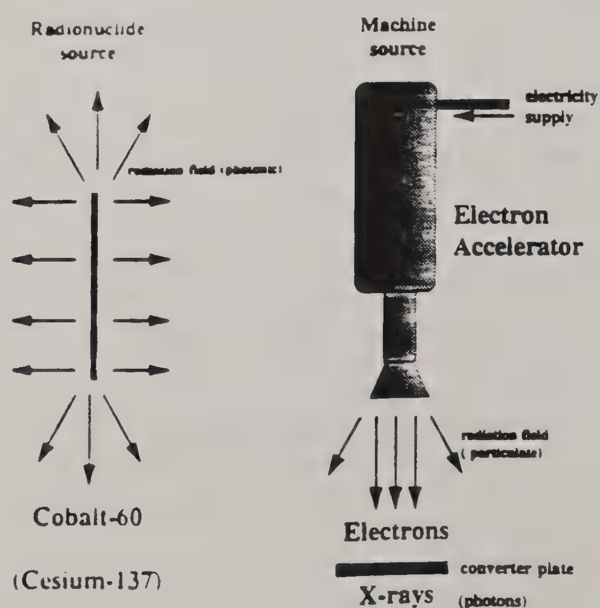


Figure 3

Source Option Comparisons

Radioisotopes

- Advantages
  - simple and reliable
  - good penetration characteristics
  - low power is relatively cheap
  - easily incremented
    - start small and grow as needed
  - dominant power source for commodity irradiators worldwide
    - large experience base
    - supplier of cobalt-60 has proven track record
  - cobalt metal is very stable
- Disadvantages
  - can't turn off
  - isotropic (can't control direction of emission, except by collimation)
  - perceived waste disposal problem
  - potentially limited availability
    - [illegible] single sourced
  - linear power:cost relationship (high power is relatively expensive)
  - cesium salt is soluble
    - for this reason cesium is not regarded as a suitable source for commercial irradiation facilities

Figure 4

Source Option Comparisons (cont'd)....

Machine Sources

- Advantages
  - controllable power and energy levels
    - very high dose rates possible
  - capability of switching between electrons and x-rays
  - directional
    - more efficient utilization of source energy
  - 'on\off' feature
  - no preceived waste disposal problem
  - non-linear cost-power relationship
    - scale up in cost lags behind scale up in power
  - multiple suppliers / advantage of competition
- Disadvantages
  - high tech / less reliable / more maintanance
  - high power, high energy machines relatively new
    - limited experience base (but increasing steadily)
  - low power is relatively expensive
  - not easily incremented
    - must buy complete machine (part of one doesn't work)
  - electrons have limited penetration ability
  - conversion to x-rays is inefficient (< 10%)
  - sensitive to cost of electricity

Figure 5

Effect of irradiation on insect reproduction

- ICGFI Code of Good Irradiation Practice for Insect Disinfestation of Cereal Grains 1991
  - 0.5 kGy recommended for grains
  - < 0.5 kGy can be used if only more radiation sensitive beetles are present
- Zakladnoi, G.A. USSR 1987
  - 0.2 kGy recommended for grain disinfestation
- Chuaqui-Offermanns, N. AECL Research 1987
  - Review of radiation sensitivities of insect pests found around globe
  - 0.2 to 0.50 kGy controls most pests
    - immediate sterility
    - death in a few weeks

Figure 6

Equivalence of gamma and e-beam irradiation for insect inactivation

- Direct comparison (Russian work)
  - *Tribolium confusum*
  - *Sitophilus granarius*
  - *Rhizopertha dominica*
  - *Oryzaephilus surinamensis*

........sensitivity same to both gamma rays and high energy electrons

- Review of literature
  - No difference between gamma and electrons

Figure 7

Comparative radiobiology......suspension cultures

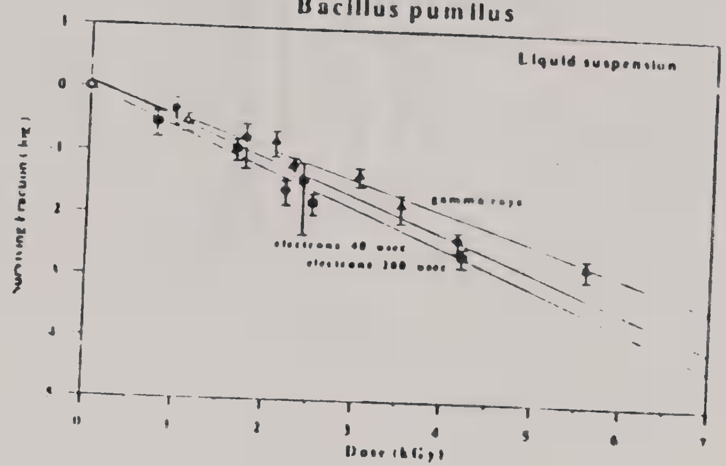


Figure 8

Comparative radiobiology......dried films

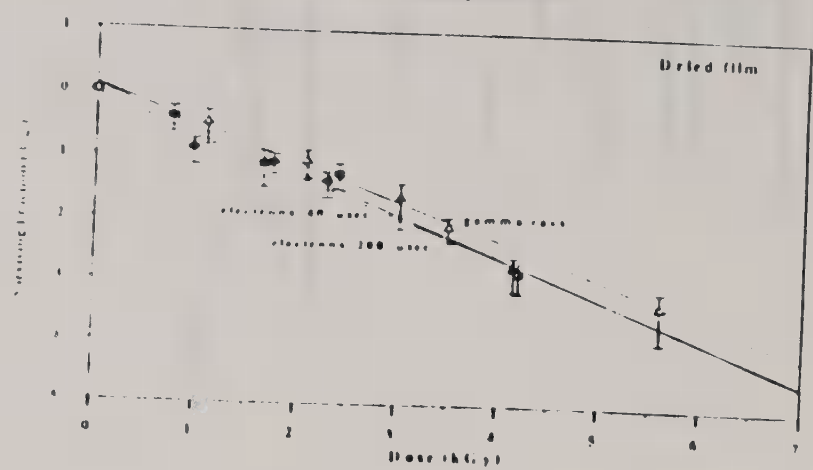


Figure 9

Comparative radiobiology.....liquid suspension

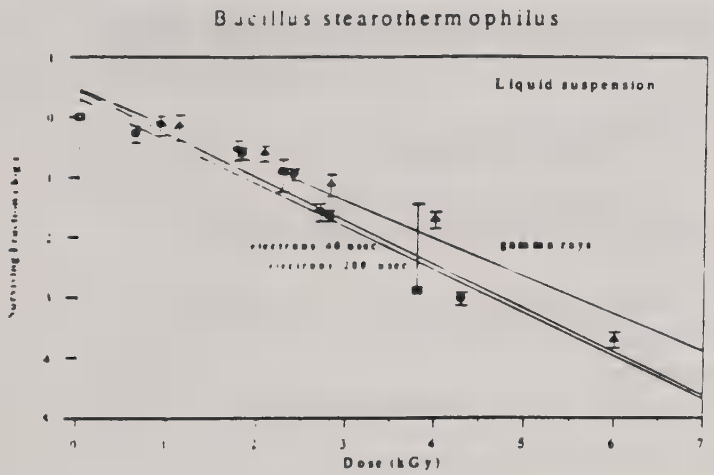


Figure 10

Comparative radiobiology....dried film

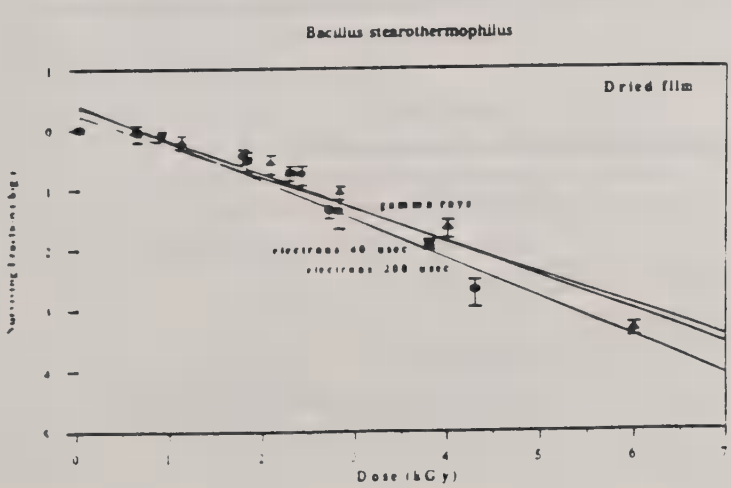


Figure 11

End-use quality of irradiated grain......

- Examined effects of gamma rays and high-energy electrons on breadmaking quality of two canadian wheat cultivars
  - Neepawa and HY320
  - 10 doses between 0 and 5 kGy
  - moisture contents of 10% and 14%
  - post irradiation storage times of 0 and 4 months
- Analyzed
  - Milling properties
  - Flour properties
  - Baking properties
  - Electrophoresis of protein fractions (gliadins and glutenins)

Figure 12

End-use quality of irradiated grain......

- Results
  - No effect on milling properties
  - No significant effects on flour properties
    - slight increase in starch damage at higher doses
  - No significant effects on baking properties for doses < 1 kGy
  - No effects on SDS-PAGE patterns of both reduced and unreduced samples
- <u>Conclusion</u>

  At doses appropriate for disinfestation the end-use quality of the grain was not deteriously affected

Ref: Ng, P.K.W., Bushuk, W., and Borsa, J. Can Inst Food Sci Technol J vol 22 pp 173-176, 1989

Figure 13

Conclusions re Technical Effectiveness....

- Irradiation can be used to inactivate insects in grains and other commodities
- Both gamma and e-beam irradiation are equally effective
  - both inhibit insect reproduction at equivalent doses
  - both have similar biological effects on microbial organisms
- Both types of radiation treatment are without significant deleterious effect on end-use characteristics of wheat and flour
  - at doses required for disinfestation

> Thus, technically, irradiation is an effective method for insect disinfestation in grain

Figure 14

Cost Analysis: The approach

- Identify all the variables which impact on the cost of processing a particular commodity
- Link the variables into a cost model
  - spreadsheet and computer
- Reference case
  - Assign values to each of the cost model variables appropriate to a desired scenario
  - Calculate a processing cost for that scenario
- Sensitivity analysis
  - Explore the cost function <u>in the region around the reference case operating point</u>
    - To permit calculation of processing cost for situations where one or more of the cost model variables differs from the reference case value
  - Identify the most significant cost variables
    - Allows optimization of the facility with respect to cost effectiveness

Figure 15

Variables included in the e-beam cost model

Financial

Capital costs

- Accelerator and controls
- Shielding
- Building
- Product handling system
- Project management
- Training

Operating costs

- Amortization time
- Interest rate
- Operator wage rate
- Handler wage rate
- Electricity price
- Building operation
- Maintenance / spares

Physical System

- Beam energy
- Beam power
- Electricity consumption
- Beam utilization efficiency
- Product thickness
- Facility utilization factor
- Dose
- Product density
- Maximum throughput capacity
- Number of operators
- Number of handlers
- Workdays per annum
- Shifts per day

Figure 16

E-beam: Reference case for grain

Reference case specifications

beam	50 kW	10 Mev
product density	0.7 g/cm^3	
beam utilization efficiency	55 %	
dose	0.3 kGy	
schedule	365 d/a	3 shift/d
facility utilization factor	100 %	
cap cost		
.........equip	5715 $K	
....shield. bldg	1279 $K	
interest rate	10 %	
amortization (yrs)	15 (equip)	20 (bldg)
electricity price	4 cents / kWh	
power requirements	500 kW	
operators per shift	1	
handlers per shift	1	

Reference case cost...0.55 $ per tonne

Figure 17

E-beam: Processing cost vs facility utilization factor

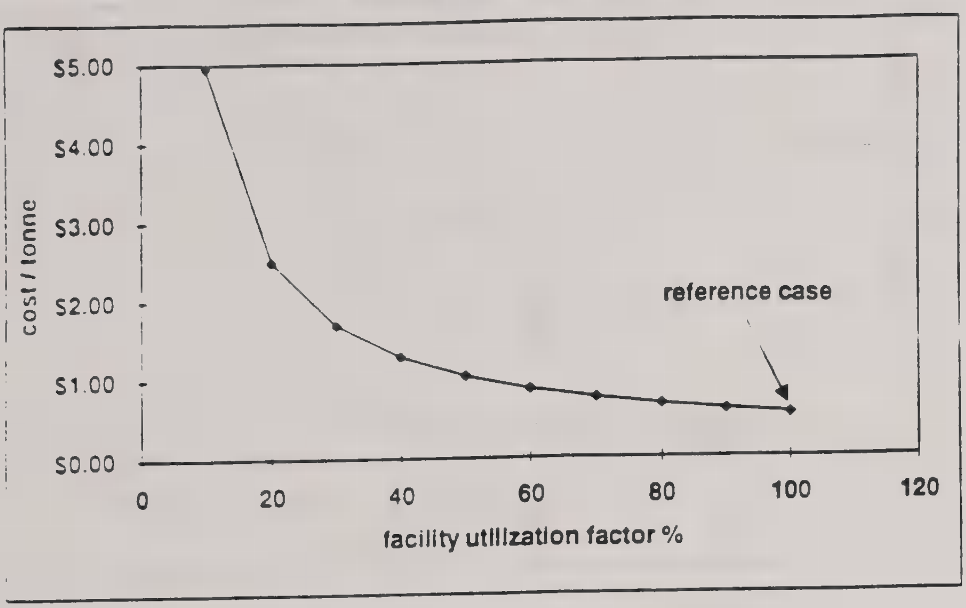


Figure 18

E-beam: Grain irradiation cost as function of annual throughput

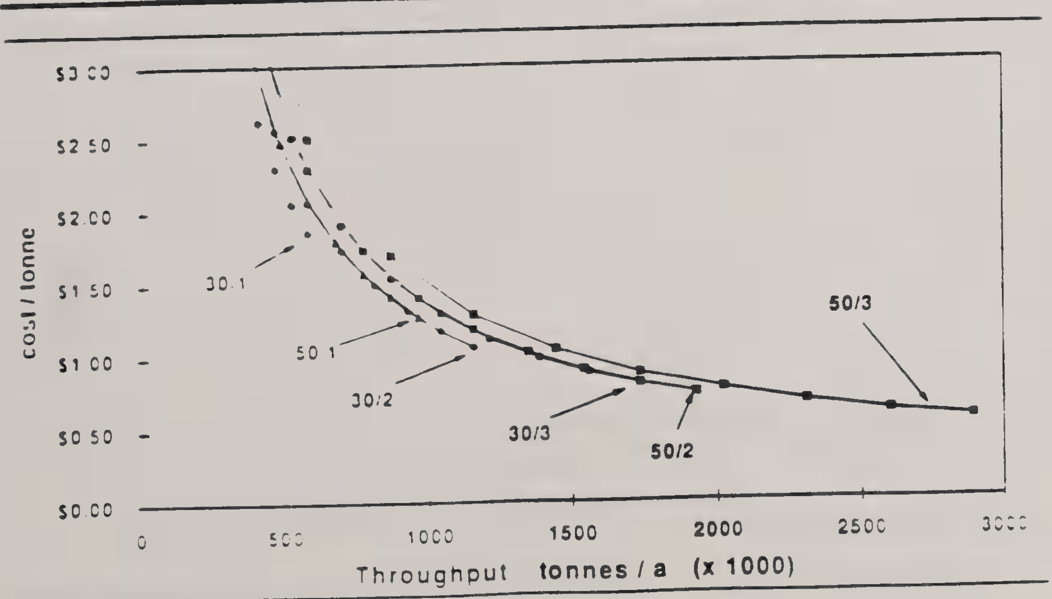


Figure 19

E-beam: Processing cost vs dose

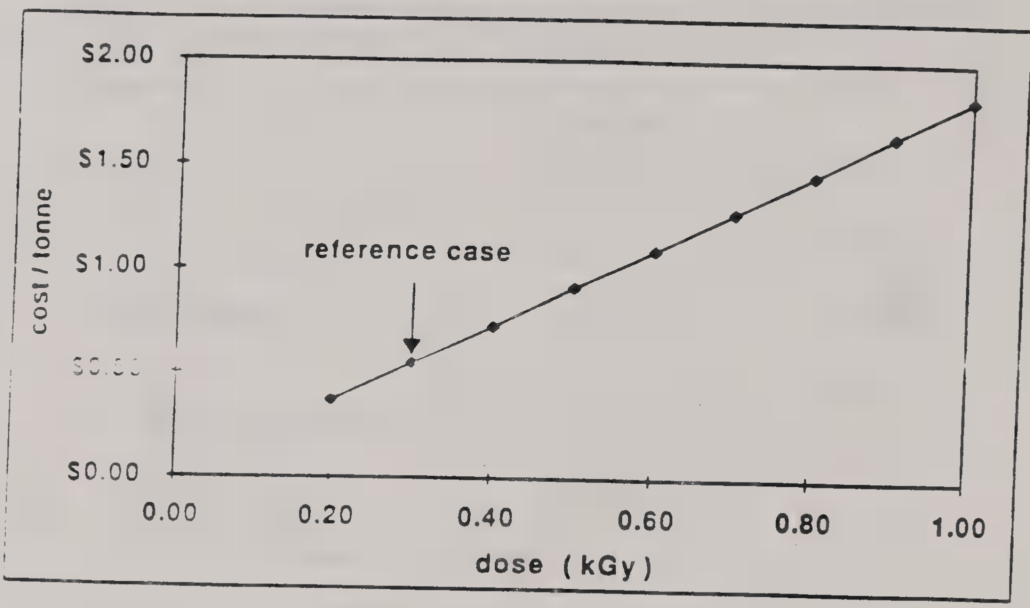


Figure 20

E-beam: Processing cost vs equipment capital cost

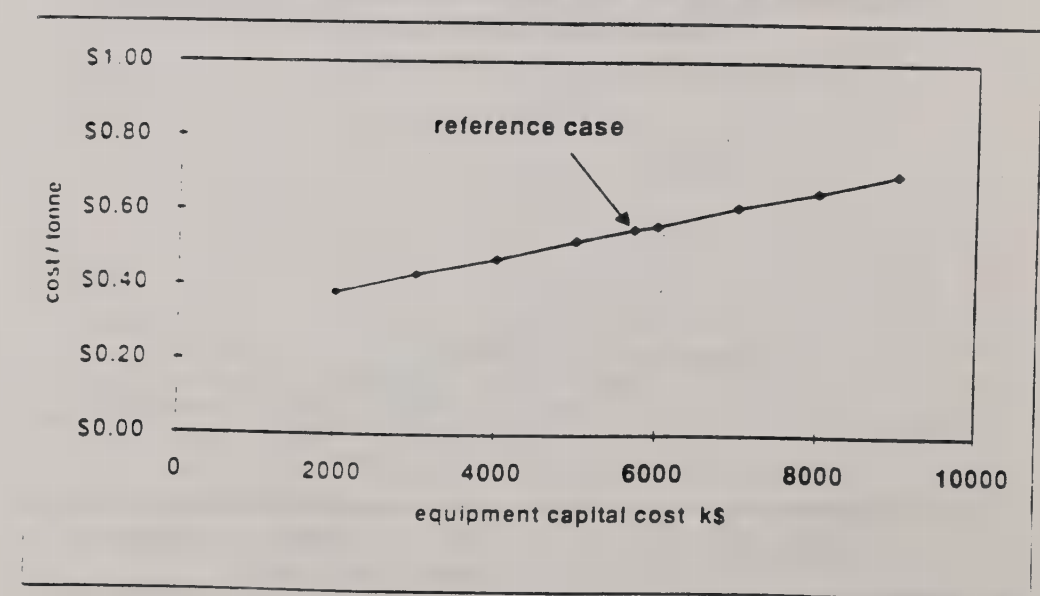


Figure 21

E-beam: Processing cost vs interest rate

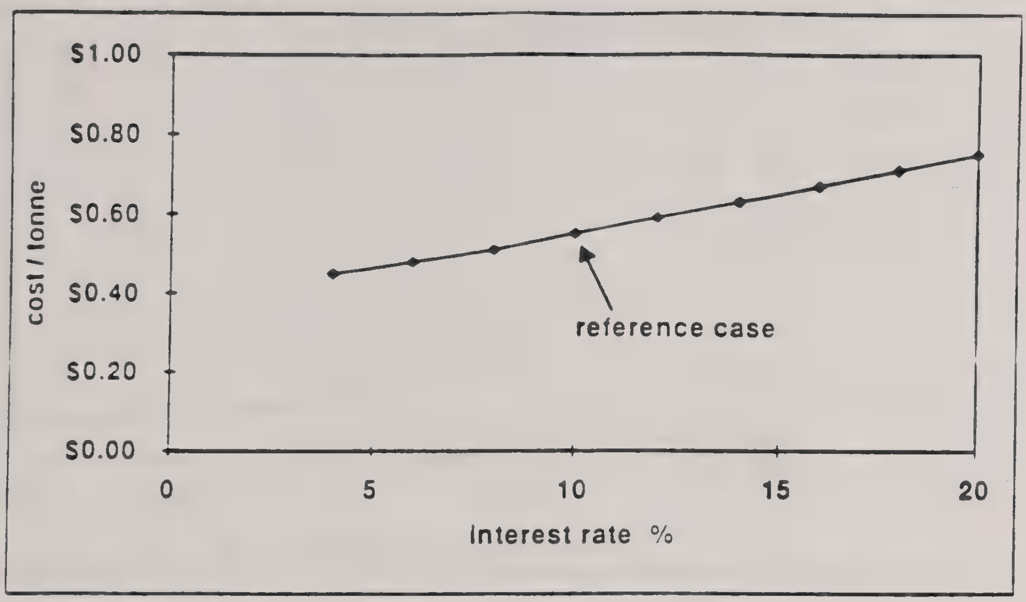
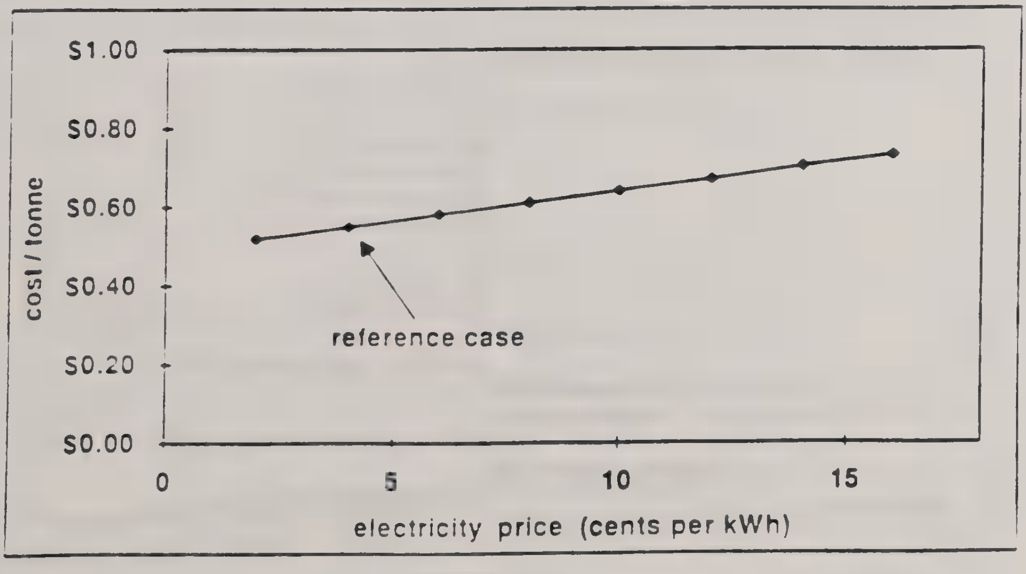


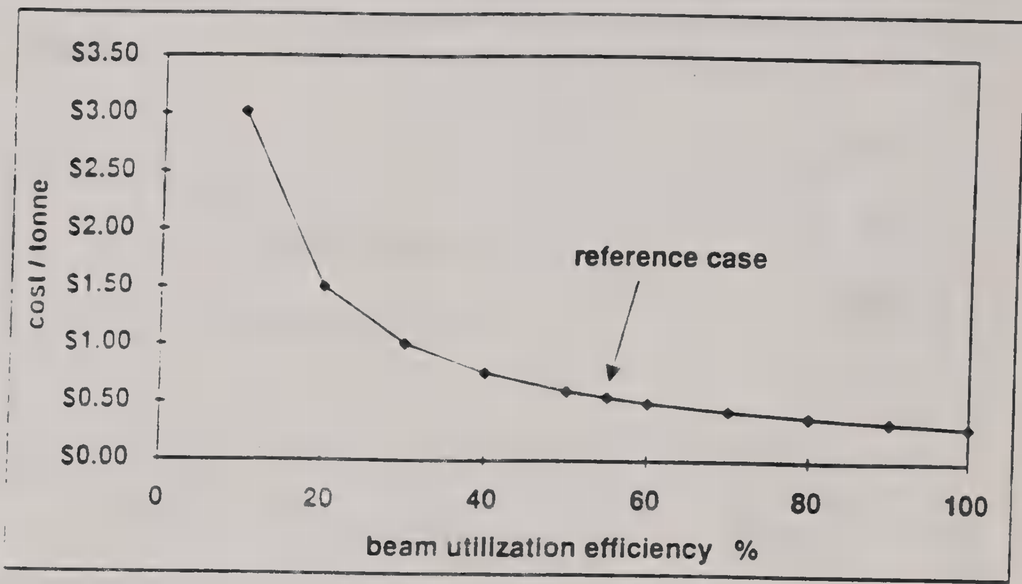
Figure 22

E-beam: Processing cost vs electricity price



E-beam: Processing cost vs beam utilization efficiency

Figure 23



E-beam: Summary of Sensitivity Analyses

Figure 24

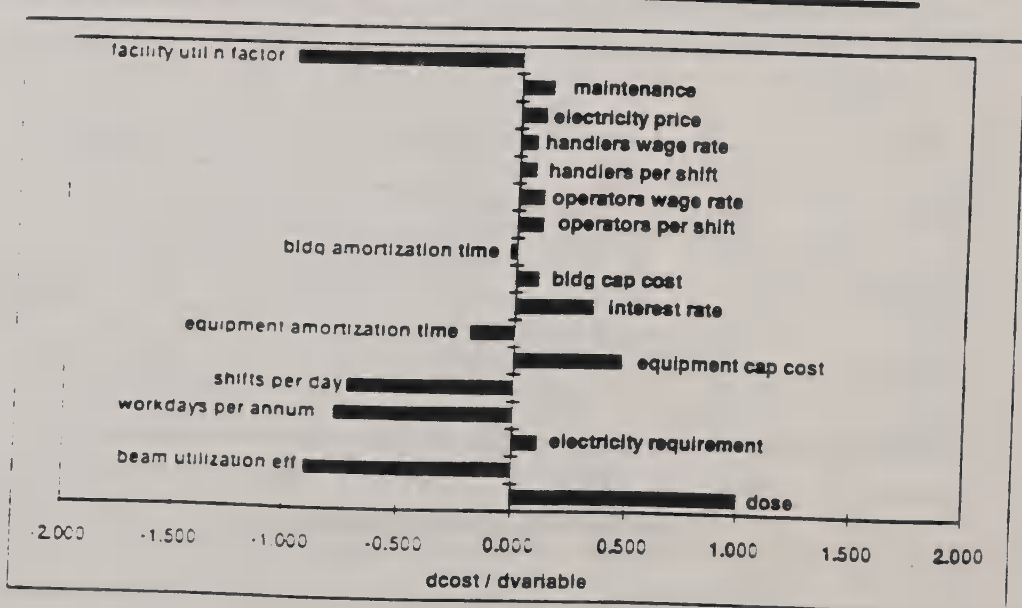


Figure 25

Gamma Facility Cost Analysis

Reference Case for Gamma Irradiator for Grain (Costs in US dollars)	
Design Capacity (kmt /a)	1000
Dose (minimum) kGy	0.3
Efficiency (usefully abs energy; %)	35
Shifts per day (@ 8 h)	3
Days operation per annum	365
Price of cobalt-60 ($/Ci)	1.63
Cost of cobalt-60 (k$)	2985
Cost of irradiator (k$)	500
Shielding cost (k$)	600
Cost of product handling equip (k$)	200
Misc cap costs (startup, other) (k$)	75
Salary of RSO (k$)	45
Operators per shift	1
Operator wage rate ($/h)	15
Product handlers per shift	1
Product handlers wage rate ($/h)	10
Supplies, maintenance, misc	25
Interest rate	10
Amortization time (a)	15

Reference Case Processing Cost = $1.23 /mt

Figure 26

Gamma:Processing cost for different throughputs

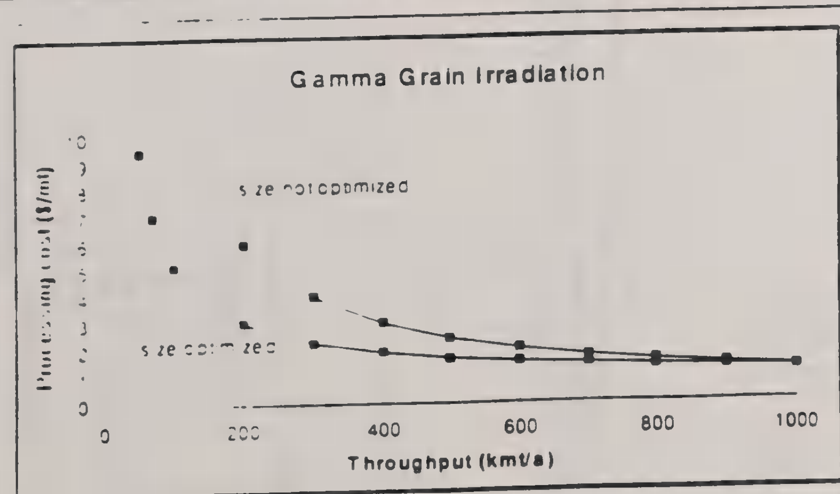


Figure 27

Gamma: Processing cost vs dose

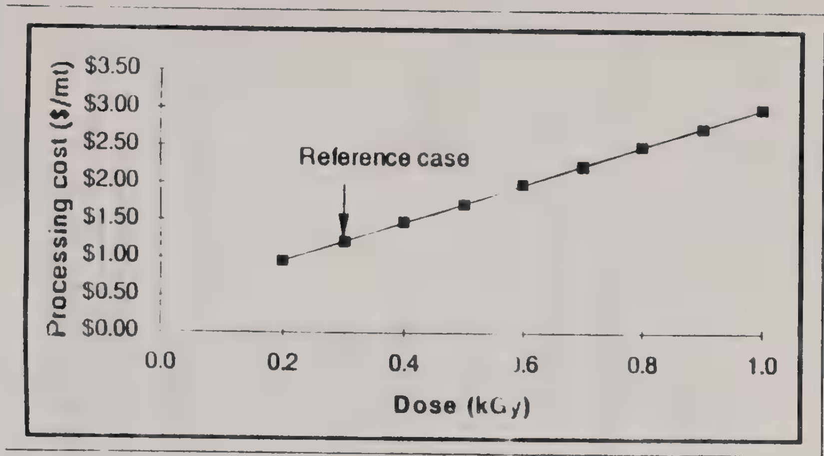


Figure 28

Gamma: Processing cost vs efficiency

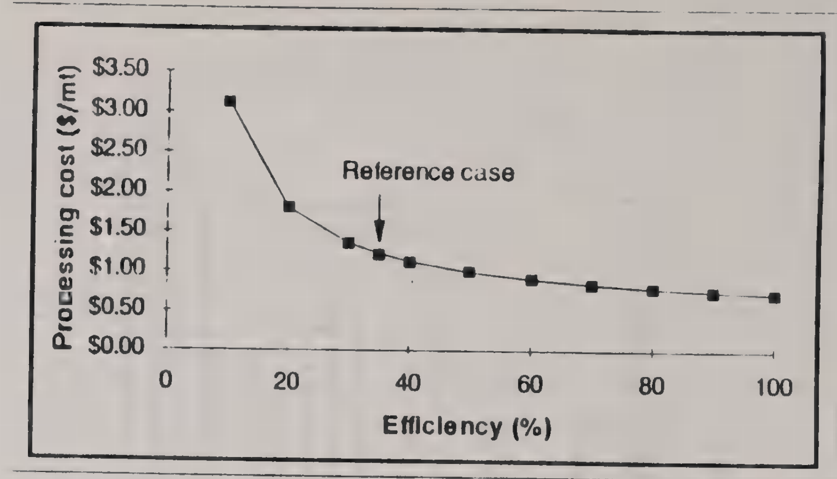


Figure 29

Gamma: Processing cost vs cobalt-60 price

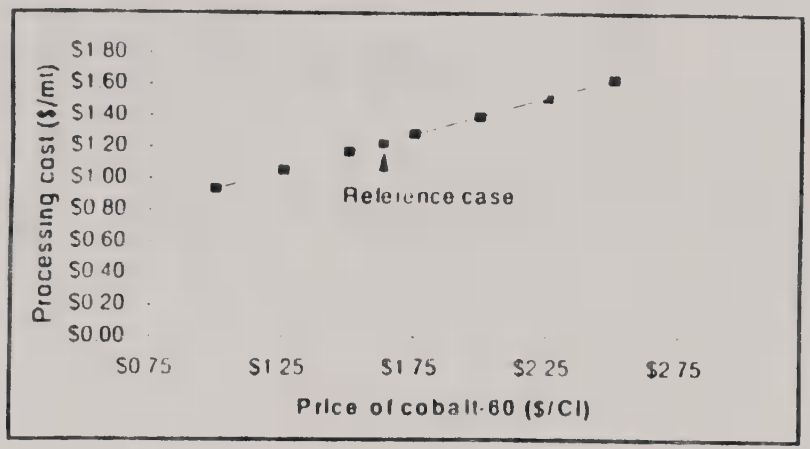
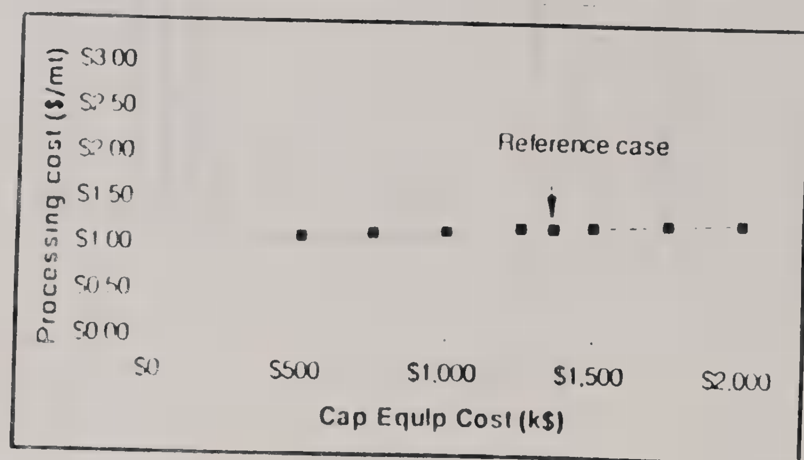


Figure 30

Gamma: Processing cost vs Cap Equip Cost



Note: The cost of the cobalt-60 is not included in this variable

Figure 31

Gamma: Processing cost vs interest rate

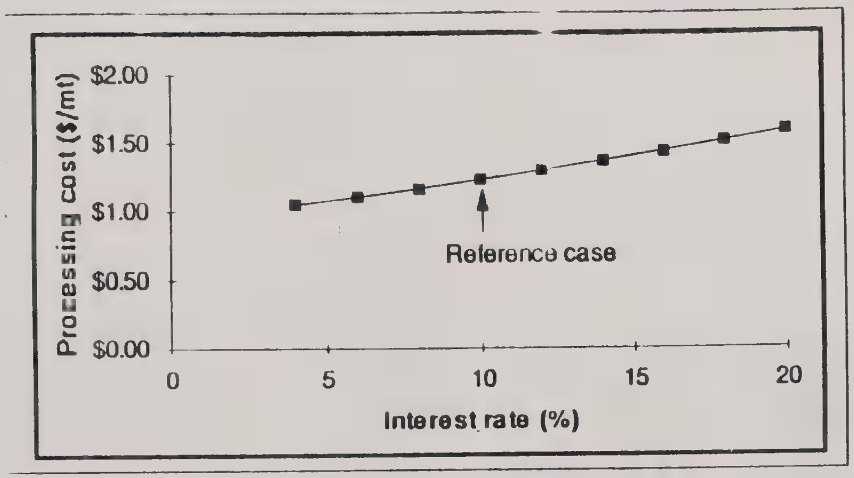


Figure 32

Gamma: Processing cost vs amortization time

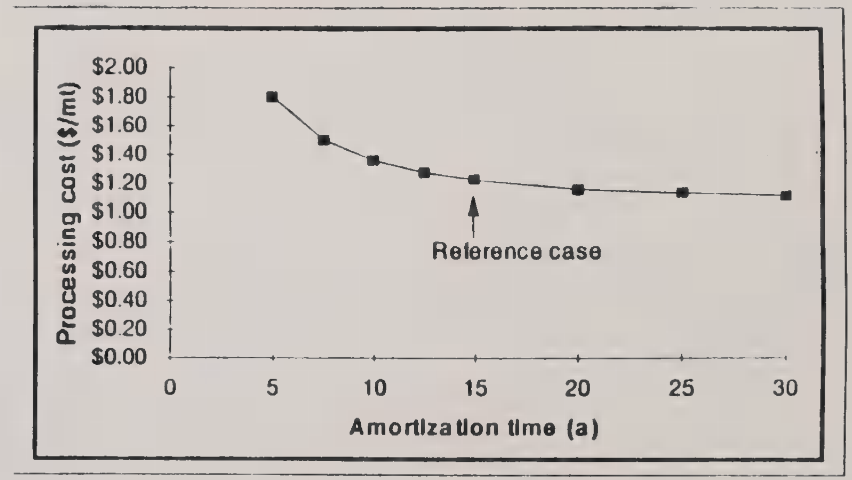


Figure 33

Gamma: Processing cost vs operating days per annum

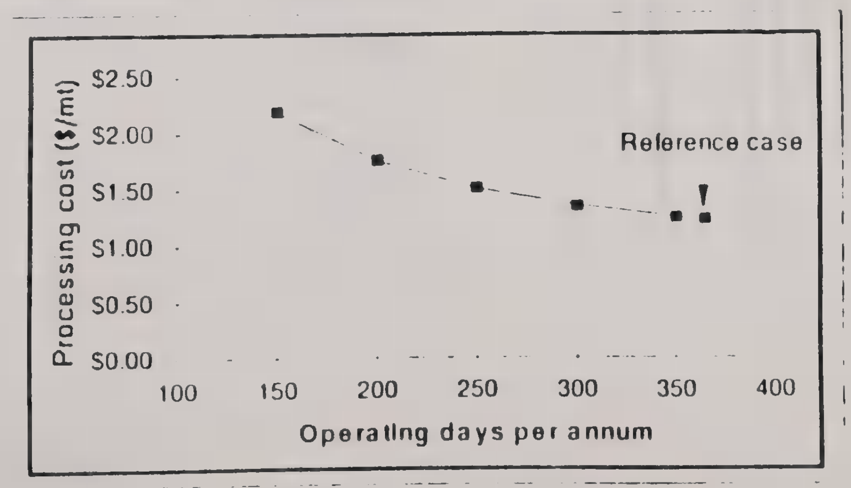
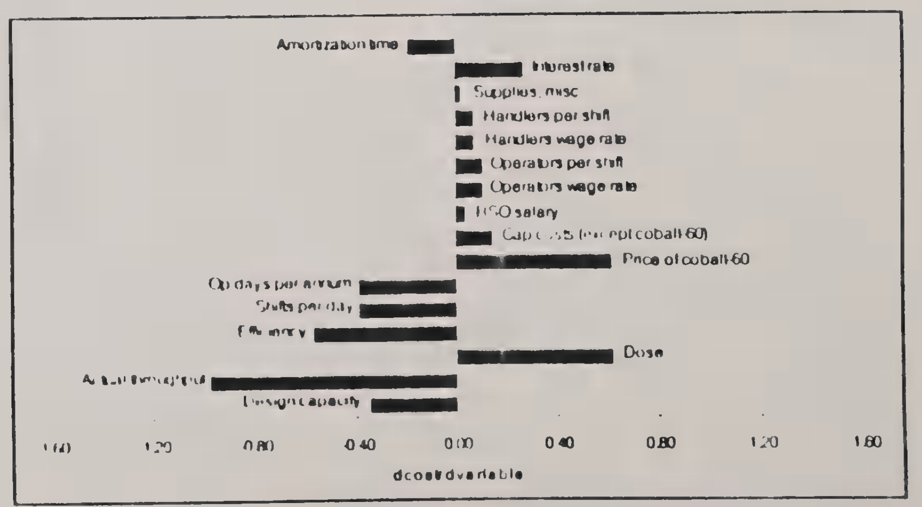


Figure 34

Gamma: Summary of Sensitivity Analyses



Note: These particular values are only valid in the near vicinity of the selected reference case

Figure 35

Summary and Conclusions

- Irradiation between 0.2 and 0.5 kGy appears to be an efficacious treatment for insect disinfestation in grains and other commodities
- At doses appropriate for disinfestation, neither gamma nor electron irradiation produces any significant harmful effects on the end-use characteristics of wheat and flour
  - effects on other commodities have to be evaluated on a commodity by commodity basis
- Costs for treatment appear to be very reasonable, at annual throughputs common to commercial practice
- Careful analysis of costs is necessary to identify the cost variables which most affect a given facility, and to optimize the cost-effectiveness of the facility

INVESTIGATION OF PHYSIOLOGICAL WAYS TO DETERMINE WHEN INSECTS HAVE BEEN IRRADIATED WITH IONIZING RADIATION

by

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Investigation of Physiological Ways to Determine When Insects have been Irradiated with Ionizing Radiation

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INTRODUCTION

The objectives of our research have been to determine if anatomical, physiological or biochemical changes can be identified that will indicate exposure of insects to irradiation, and if so, whether the changes are indicative of the dose of irradiation received. Availability of an indicator of commodity irradiation could be helpful to the food and commodity industry. For example, if quarantine-security insects are detected in irradiated food, then it is important to determine if the insects have been irradiated with sufficient dose to prevent reproduction.

Rahman et al. (1990) and Rahman et al. (1992) showed that the supraoesophageal ganglion of several species of tephritid fruit flies was reduced in size when young larvae were irradiated with a series of dosages ranging from about 5 Gy to 150 Gy, while the proventriculus was not affected and its size could be used as a reference measurement. During the past year we have investigated whether there were similar effects of irradiation upon the supraoesophageal ganglion of the Caribbean fruit fly.

We thank the International Atomic Energy Agency, Vienna, for grant support to pursue this work. We are investigating the following with the Caribbean fruit fly as a model insect.

(A) The influence of irradiation dose upon the supraoesophageal ganglion, nerve cord, and selected imaginal disks in larval flies.
(B) The influence of irradiation on enzyme activity in larval insects.

MATERIALS AND METHODS

<u>Insects</u>.

Eggs or larvae of the Caribbean fruit fly, <u>Anastrepha suspensa</u> (Loew), were obtained from the mass rearing facility at the Florida Department of Agriculture and Consumer Services in Gainesville, Florida. Eggs about to hatch, and hatching larvae, were irradiated with a ^{137}Cesium source at the USDA laboratory in Gainesville.

Larvae were dissected and the area of the two hemispheres of the supraesophageal ganglion (dorsal aspect) and of the proventriculus were calculated from length and width measurements with an ocular micrometer in the eyepiece of a stereo dissecting microscope. Areas were calculated by the formula for an ellipse (πab). Ten larvae were dissected and measured at each irradiation dose level. The entire experiment was repeated 3 times (i.e., 3 separate groups of larvae were irradiated). Tissues for SEM studies were prepared by the HMDS technique for air drying (Nation 1983).

RESULTS AND DISCUSSION

The central nervous system and associated structures in mature 3rd instar larvae of the Caribean fruit fly, Anastrepha suspensa (Loew) (Diptera: Tephritidae), were dissected and measured. Structures that were observed were the supraoesophageal ganglion or "brain," the short ventral nerve cord, the ring gland, and imaginal disks for the adult structures of compound eyes, antennae, legs and wings. The proventriculus near the junction between fore- and midgut was measured as a reference for the measurements of the supraoesophageal ganglion.

Larvae that were irradiated with at least 50 Gy at hatching presented several types of abnormalities. The ventral nerve cord was usually elongated and very distorted in shape, rather than being short and stubby as in normal larvae. The supraoesophageal ganglion was very small relative to the proventriculus, and adult leg imaginal disks were either very small or not evident at all. The imaginal disks for adult compound eyes were very small and distorted in shape. Larvae with these abnormalities often survive to pupate, although many die before reaching the pupal stage. They are unable to form normal adult structures such as legs, wings, eyes, gonads, and other adult structures because of damage to the imaginal disks.

The ratio of supraoesophageal ganglion (brain) area/proventriculus area of late 3rd instar larvae is inversely correlated with the irradiation dose given at hatching. This is in agreement with the previous work of Rahman et al. (1990), Rahman et al. (1992), and Jessup et al. (1992) on several tephritid species. The area of the proventriculus is essentially independent of the irradiation dose, however, and thus becomes a constant factor for establishing the area ratio. This is also in agreement with previously published work (Rahman et. 1990, Rahman et al. 1992, and Jessup et al. 1992).

The supraoesophageal ganglion grows in control larvae during successive days after hatching, but much of the growth is inhibited as a result of irradiation with 50 Gy. Measurements made in the 1st instar, and again during the first day of the 2nd instar, show that the supraoesophageal ganglion grows very little during these 2 to 2.5 days of life. Substantial growth begins at about the 3rd day of larval life, and continues steadily thereafter through the first day following pupation. At about 25°C a larvae hatches from the egg in about 3 days. The 1st day and most of the 2nd day of larval life is the first instar. Late on the 2nd day it molts into the 2nd instar, and sometime on the 4th day, it molts again into the 3rd instar. Some larvae may form pupae by the 6th day after hatching, but many pupate on the 7th day. The imaginal disks for compound eyes are present already in the 1st instar, but leg disks (present, but too small to see in the 1st instar) do not start to grow enough to be visible until the 1st day of the 3rd instar. Growth of the imaginal disks may be influenced by hormones secreted from the ring gland.

Growth of the proventriculus is similar to that of the supraoesophageal ganglion, but a major difference is that maximum growth of the proventriculus is reached at about day 5 of larval life It is not known at present why growth of the proventriculus is unaffected by the radiation dose; it is possible that all the cells needed for its development are present at hatching, and that the cell only grow by enlargement rather than by dividing. Cells in the brain and imaginal disks grow both by cell enlargement and by cell divisio

Although the dissections are not especially difficult to perform, some practice and skill are required. Moreover, there are several factors that can make the ratio of supraoesophageal ganglion area divided by proventriculus area less useful as an indicator of irradiation. First of all, the proventriculus changes shape at pupation. This makes intrepreting the supraoesophageal ganglion area/proventriculus area ratio difficult, if not impossible, after pupation. Secondly, the ratio of areas is not indicative of irradiation exposure at 50 Gy until the 2nd day of the third instar (about the 5th day of larval life in _A_. _suspensa_). Probably not enou growth has occurred during this time for the irradiation to have influenced cell divisions.

There are, however, other very good indicators of irradiation after a successful dissection, such as the failure of the imaginal disks to develop, and distortions of the ventral nerve cord. Locating these i a dissection, however, requires skill. It likely will be very difficult for quarantine inspectors to utilize the supraoesophageal ganglion/proventriculus ratio to determine if radiation has occurred.

Clearly a simpler and more definitive indicator of irradiation would be desirable. The degree of melanization that fruit fly larvae undergo after death (as by freezing) may provide a simpler indicator. During the course of the supraoesophageal ganglion studies, we sometimes froze control and irradiated larvae until they could be dissected and measured. Serendipitously, we found that control larva began to blacken (melanize) within minutes upon removal from the freezer, as did larva irradiated with 5 Gy or 10 Gy, while larvae irradiated at hatching with 20 or more Gy melanized very little if any, even after exposure at room temperature for hours. The process of melanization in insects is a common reaction, and is involved in the formation of the puparium, as well as in many other processes of pigmentation in dark brown or black insects. Irradiation probably inhibits one or more of the chain of enzymatically controlled reactions leading to melanin formation in irradiated fruit fly larvae.

Darkening or melanization occurs in most insects at injury sites, or after death. Melanization is strongly inhibited in Caribbean fruit fly larvae by high doses of irradiation, but this observation needs to be more thoroughly investigated. We are not certain how indicative it is of radiation dose. Lack of melanization, however, does seem to indicate a dose of at least 20 Gy or greater. The immediate appeal of the test is that it is extremely easy to perform, and requires no equipment or training. If a quarantine inspector found a 3rd instar larva (this is likely to be the stage found simply because of size), the larva could be placed in a freezer for a short time to kill it and activate the melanization reaction. Upon removal from the freezer, the larva could be observed for color change, if any. The color change can be conveniently recorded by photography. Since the recommended dose for treatment of a commodity subject to a fruit fly quarantine restriction is 150 Gy, the test might be a "yes" or "no" with respect to treatment. Additional studies will be required to determine the validity and applicability of this test for practical use.

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RAHMAN, R., A.D. BHUIYA, S.M.S. HUDA, R.M. SHAHJAHAN, G. NAHAR, AND M.A.WADUD. 1992. Anatomical changes in the mature larvae of two Dacus spp. following irradiation, pp. 133-139 in Use of Irradiation as a Quarantine Treatment of Food and Agricultural Commodities, Proc. of Final Research Co-Ordination Meeting, Kuala Lampur, Malaysia, 27-31 Aug. 1990.

AND NOW FOR SOMETHING COMPLETELY DIFFERENT: THE *GRAY*STAR™ OPTION*

by

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Suite 103
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The Process Radiation Industry is now about thirty years old. Those of us around back then when it all started had our hopes and dreams all sorted out. Some of them have been realized, others not. At this point, however, I will not bore you with a long list of successes and failures. I believe that most of you are now aware of the fact that at long last we appear to be on the threshold of the commercialization of Food Irradiation — our greatest dream. Irradiation is now being *seriously* considered for reducing the incidence of foodborne disease, and as a viable alternative for quarantine treatment. In both cases these applications are being driven by *need*. That has not always been the case.

The big question being asked here today is whether irradiation is a *practical* alternative. By *practical* I mean: Will the food and produce industry actually use it ? They will, provided our Government promptly furnishes approvals, *and* these three questions are resolved:

- Will the public accept irradiated food ?
- Are the processing costs reasonable ?
- Will the equipment and systems required be compatible with existing Food and Produce Industry standards ?

The first question has been answered in spite of all the cynicism, although it will take some time before the positive results of recent sales, market tests and polls are disseminated. Our rather extensive studies indicate that radiation processing costs for quarantine treatment will be a little less than one cent per pound. This is comparable to methyl bromide processing costs, and should not be an impediment to commercialization. The third question, however, addresses what could be a fatal flaw. It is my contention that for the most part available irradiators are not compatible with the needs of the Food and Produce Industry. Here is why:

Most isotope irradiators now in use are based on designs and concepts originally developed by the Government (United States and/or Canada). Their designs have evolved over many years, mostly in response to ever tightening Government Regulations. Some changes were made in answer to materials handling needs. For the most part, however, the traditional "Package Irradiator" looks pretty much as it did in the 1960's. They all use cobalt-60, large concrete walled chambers, water storage pools, intricate personnel interlock systems and complex automatic/semi-automatic tote/carrier conveyors. Safety, support and validation systems have become far more sophisticated, but their principles remain unchanged. They also employ a reasonably large number of very highly trained people. While the contract service irradiation companies are able to cope with these realities, most firms that presently employ fumigation techniques are disinclined to become involved with a "Nuclear" operation.

During this period we did not see any revolutionary developments in food irradiator design. For decades gamma irradiator designers confined their efforts to scribbling on the backs of napkins (with a few patents filed here and there). Accelerator manufacturers extolled the "obvious" virtues of the electron beam over the gamma photon. A countless number of international meetings were held to listen to the same old stuff articulated by the same old players. After examining our Workshop Program, I must admit that it does look a little familiar.

Developing a new type of irradiator specifically for food is a very expensive proposition. Industry will not invest the required capital until they are convinced the market is truly there. In this instance the market is definitely **not** "there" **until** the necessary approvals are issued by the appropriate Government agencies. Case in Point: A few years ago the Food and Drug Administration approved the irradiation of poultry for the control of foodborne disease. Many potential investors ask why the process is only now becoming commercial and is still somewhat limited in scope. They are of course not aware of the approvals required from USDA, or of the time consuming details that must be resolved between the processor and USDA to obtain those approvals. It takes companies with great courage, such as Vindicator, to break the ice.

Having been in this field for 36 years, and having designed, built and operated many "conventional" irradiation facilities, I am well aware of their shortcomings. Five years ago we started work on a new type of irradiator, designed to resolve these problems. We literally reinvented the irradiator. We call it the GRAY*STAR™.

All of the commercial irradiators in use today are large centralized "general purpose" facilities, ranging in cost from $2,000,000 to $3,500,000, not including radiation source material, which is considerable. They are designed as general purpose units because they must operate for three shifts a day, almost every day of the year, for them to be economically viable. Generally speaking, as an irradiators's output increases, the unit processing cost decreases. That is because almost all of the costs are fixed except for the radiation source material. For the most part, large centralized facilities are intended to handle products which require radiation doses many times higher than those for disinfestation.

All of this indicates that there is a need for a **small** decentralized irradiator. However, the problems inherent in the design of such a unit are formidable. We utilize cesium-137 rather than cobalt-60. The cesium is "stored" in air rather than water and therefore does not suffer the thermal shock that it would in a conventional water storage facility. The unit is "self-contained" and the shipping container is an integral part of the irradiator. Only one standard sized pallet is irradiated at a time. The only materials handling equipment required is a simple pallet jack.

To fulfill all of the requirements for a truly "user oriented" unit, the following criteria applied. The GRAY*STAR™ irradiator incorporates all of them.

INHERENTLY SAFE WITH REGARD TO RADIATION

The concept of "inherently safe" is replacing older ideas such as "fail safe" - a term that has been so misused and misunderstood that it no longer has any meaning. The best way to define "inherently safe" is with an example: A boat made from a foamed plastic will not sink even if it is cut into pieces. It is inherently safe with regard to sinking. Note that it will not prevent someone from falling into the water and drowning. It is only safe from sinking. The GRAY*STAR™ irradiator was designed in such a way that it will not emit radiation regardless of the treatment it receives (or doesn't receive). Since it doesn't matter what the operator of the unit does, a great deal of sophisticated training in radiation safety is not required. The irradiator operator is removed from the safety system. In effect, human error has been eliminated from the safety equation.

PREFABRICATED

The GRAY*STAR™ irradiator was designed as a piece of equipment that is prefabricated rather than a large "Irradiation Facility" that requires the construction or major modification of a building. Such major changes require site plan, zoning, and planning board approvals at the local government level. These can result in delays and complications so expensive that the entire project becomes economically unattractive. The GRAY*STAR™ is a piece of equipment, not a facility, so that approvals for its use come only from the appropriate federal regulatory agencies. As piece of equipment is also considerably easier to finance, and because it is prefabricated it is recoverable. GRAY*STAR units will be manufactured in lots, making them available on short notice.

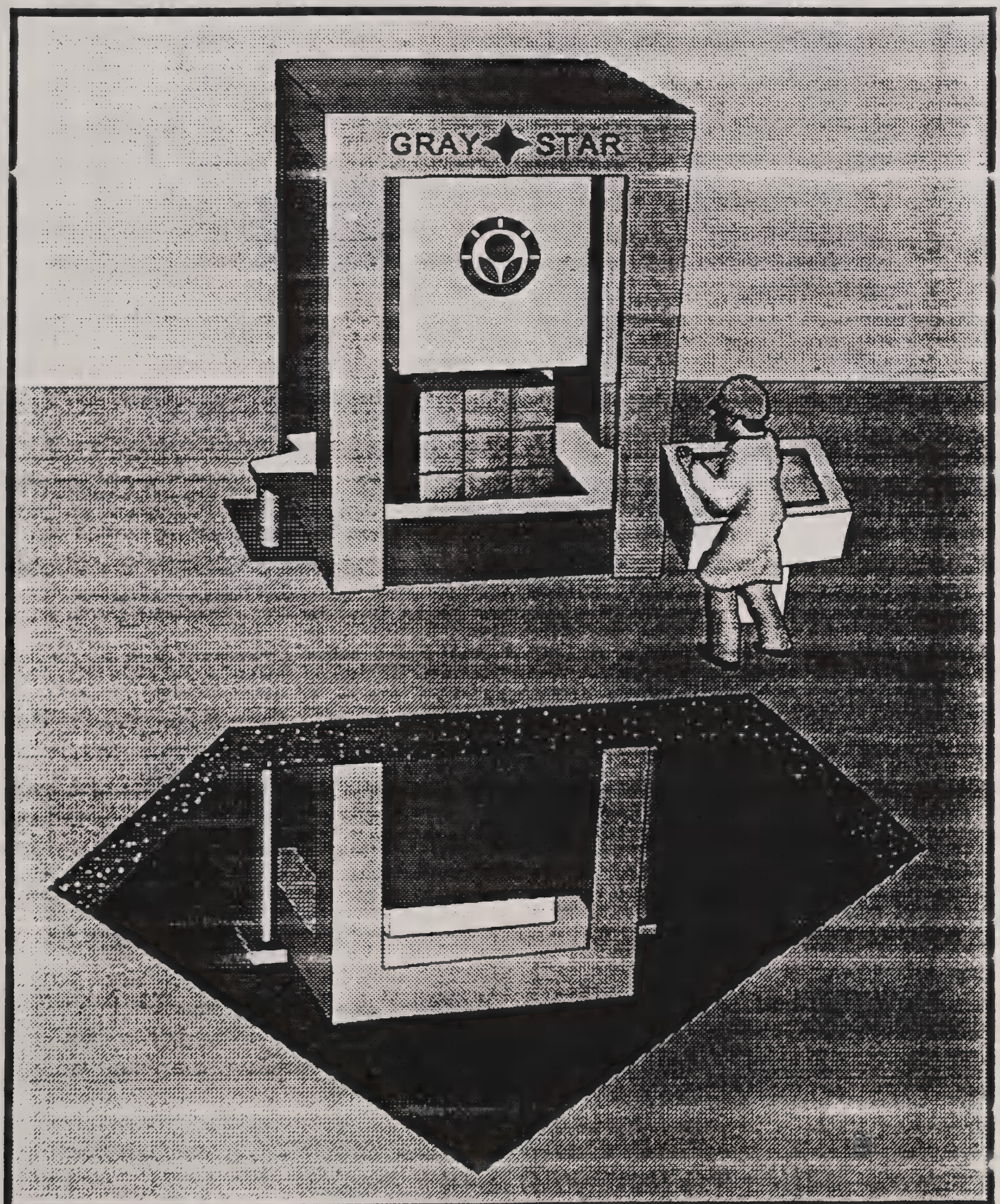
DESIGNED FOR CUSTOMER USE

All commercial production irradiators now in use are essentially "nuclear" facilities. They require extensive monitoring and control by very highly trained personnel, 24 hours per day, 365 days per year, whether or not they are being utilized. The materials handling or conveyor systems were designed to make maximum use of the radiation available rather than fitting into the users' system. Yet almost all the food treated by present chemical fumigation is done on pallets or bins. Any system that does otherwise will be contrary to the customers' experience. Any irradiator, therefore, designed for this purpose must irradiate the product on pallets or in standard bins. One might say that the GRAY*STAR™ is a more **"palletable"** irradiator.

ECONOMICALLY COMPETITIVE

The GRAY*STAR™ will irradiate product at a unit cost very close to, or less than the chemical fumigation processes now in use.

I would enjoy revealing to you precisely how we managed to accomplish these feats. Unfortunately, I cannot, because our patent attorneys obviously frown on the disclosure of certain information at this time. However, this picture will help you to understand the concept of the GRAY*STAR™ irradiator:



It took almost five years of concentrated effort to design this irradiator. This concept survived an extremely vigorous feasibility analysis. To make it work, many technical problems had to be solved. Over a period of time, five areas of technology were defined which support the design concept. These are code named:

UNIGRAY™

The GRAY*STAR™ is a pallet irradiator, which means that the irradiator is designed so that the radiation flux can penetrate throughout four feet of material in three dimensions. The problem is similar to broiling a large roast - one wants to cook the inside without burning the outside. The UNIGRAY™ is a "breakthrough" invention conceived by Russell N. Stein, which solves this problem in a very practical manner.

VALIGRAY™

This is a device to automatically "validate" or guarantee that all parts of the product have received the minimum radiation dose required to do the job, and that no part has received more radiation than is allowed or desired. The VALIGRAY™ is automatic and does not require operator training. The GRAY*STAR™ irradiator will validate each and every pallet individually. The system will be in full conformance with all national and international codes of practice. (Those proposed as well as those in use.) There is no such device available today on the market.

GRAYLIFT™

GRAYLIFT™ is a unique design concept, which allows the GRAY*STAR™ Irradiator to operate in an inherently safe manner. Regulators, such as the U.S. Nuclear Regulatory Commission, consider this aspect of the greatest importance. It is very reassuring to us as the manufacturer, that our customers' employees can not accidentally be irradiated or endanger the public, no matter what foolish mistake they may make.

GRAYSTOP™

This is a fundamentally important invention by Russell N. Stein that prevents the radiation from "shining through the joints" of the unit. Its use, in conjunction with other well known techniques, greatly reduces the cost of manufacture and ease of operation.

GRAYCOM™

GRAYCOM™ is an electronic device and computer program directly linked to the GRAY*STAR™ operating system. This will allow regulatory bodies to monitor the operation and validation of a GRAY*STAR™ from a completely remote location. This is vitally important to Latin American countries that will irradiate produce for quarantine approval by the U.S. Department of Agriculture for shipment to the United States. At present, inspection by the USDA in the countries of origin is a very expensive and limiting factor in the production and shipment of produce to the United States (not to mention the effect on the USDA budget). Similar situations will occur in the future for shipment of produce such as citrus to countries such as Japan.

The irradiator is still under development. We anticipate that units will be routinely available a little less than two years from now. Elaborate computer programs have been developed, so that we can estimate processing costs on a case by case basis with some degree of accuracy. Over 200 case studies have been generated with this program. An example is included in this paper. I chose Hawaiian papayas as an illustration because at present it is the only commodity approved by the USDA for quarantine. As you can see a GRAY*STAR™ unit is capable of processing about 50 million pounds per year at a processing cost of six tenths of a cent per pound. A conventional pallet irradiator is capable of approaching these costs, but only when a quarter of a billion pounds of product are processed each year.

In closing I would like to make three points:

✦ There are, and will be, irradiators capable of supporting the large scale commercial use of irradiation for quarantine purposes. Whether cobalt-60, cesium-137 or e-beam are used will depend on the requirements of the specific application. The Marketplace will make that judgment. I suspect that all three methods will be employed, though not equally.

✦ Irradiation is not a substitute for Methyl bromide. It is a viable alternative to several existing processes, including methyl bromide. Even if there were no question concerning ozone depletion, irradiation would be an attractive alternative. Its application is broader, it's more effective and the costs are comparable.

✦ None of this will matter worth a kumquat if the USDA does not issue approvals for all of the appropriate commodities as soon as reasonably possible. Without these approvals, industry will not invest, and the cynics within the Government can then engage in a self-fulfilling prophecy.

GRAY*STAR CASE STUDY | 1-26-94 | A-5a

Customer
Address

Phone
fax

Unit: GRAY*STAR
Product: Hawaiian Papayas
Purpose: Quarantine --> Con't. USA
Note: Internal Study
by M. H. Stein.

PARAMETERS

Unit Purchase Price	$1,300,000	dollars
Installation + Shipment	$70,000	dollars
Initial Cesium-137 Loading	1,200,000	curies
Minimum Dose Required	150	grays
Maximum Dose Allowed	1,000	grays
Product Density	0.36	grams/cc
Labor Rate	$7.50	dollars/hour
Overhead	100	percent
Utilization	75	percent
Load-Unload Time	2.00	minutes
Season Length	270	days/year
Season Year	1	(which year?)
Maintenance & Repairs	$6,000	dollars/year
Finance Term	10.0	years
Finance Interest Rate	10.0	percent
Product Load Height	48	inches
Pallet Length	48	inches
Pallet Width	40	inches

COST ESTIMATION

0.59	cents/pound
0.13	$/cubic foot
11.89	$/ton
1.31	cents/kg
13.11	$/metric ton
7.14	$/pallet
296,156	$/year

HOURLY PRODUCTION

10,247	pounds
4,648	kilograms
5.12	short tons
4.65	metric tons
8.54	pallets
455	cubic feet
0.26	truckloads

DAILY PRODUCTION

245,940	pounds
111,556	kilograms
123	short tons
112	metric tons
205	pallets
10,931	cubic feet
6.1	truckloads

YEARLY PRODUCTION

49,802,826	pounds
22,590,064	kilograms
24,901	short tons
22,590	metric tons
41,502	pallets
2,213,459	cubic feet
1,245	truckloads

TECHNICAL DATA

Pallet Product Weight	1,200	pounds
Minimum Dose Received	150	grays
Maximum Dose Received	374	grays
Percent of Max Dose Allowed	37.4	percent
Max/Min Achieved	2.49	(U)
Irradiation Time	5.03	minutes
Total Cycle Time	7.03	minutes
Total Cycle Time	0.12	hours
Annual Processing Time	4,860	hours/year
Minimum Dose Rate	29.8	grays/minute
Minimum Dose Rate	179,065	rads/hour
Radiation Utilization Factor	7.03	percent
Overall Utilization Factor	5.03	percent
Cesium-137 Remaining	1,186,302	curies
Annual Unused Capacity	44	percent
10th Year Production Output	0.86	(factor)

COMMENTS

This process has been approved by both the FDA and the USDA.

The total output of papayas in Hawaii is from sixty to ninety million pounds per year.

COSTS

	$/year	percent
Labor	36,450	12.3
Overhead	36,450	12.3
Mainten.	6,000	2.0
Unit	137,000	46.3
Interest	80,256	27.1
TOTAL	$296,156	100.0

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THE ANIMAL AND PLANT HEALTH INSPECTION SERVICE (APHIS) TREATMENT REQUIREMENTS

by

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Plant Protection and Quarantine
Animal and Plant Health Inspection Service
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The Animal and Plant Health Inspection Service Irradiation Treatment Requirements

Gainesville, Florida
February 2-3, 1994

The only approved quarantine treatment using irradiation, the treatment of Hawaiian papayas for fruit flies, was developed and published using probit 9 as the standard for laboratory data. The standard required that all treated insects would be incapable of reproduction and that any emerging adults would be incapable of flight. It was understood that some insects would be alive at the dosage approved (15 kilorads) and that quarantine action would be taken if live insects were found upon inspection at destination. It was also understood that an applied dose adequate to kill all eggs, larvae, and pupae of the fruit flies of concern could be commercially applied within the product's resistance to phytotoxicity. This treatment has never been used in its 6 year existence, partly due to the preceding quarantine concerns and partly for economic and environmental reasons.

There is increasing interest in irradiation as a quarantine treatment, particularly as an alternative to methyl bromide. APHIS is dedicated to encouraging development of treatments, including irradiation treatments, that are scientifically sound and acceptable to the commercial community. With the present position only a few irradiation treatments could be developed and used. Many of these would be for fruit flies, and methyl bromide is the prescribed treatment for fruit flies in only a few instances. If we intend to encourage the use of irradiation it will have to include non-fruit fly pests. Most of the data presently available were developed for fruit flies, although several instances of research on other species, such as codling moth and mango seed weevil, do exist.

The following key issues arise:

1. Efficacy against the organism. We are confidant that the traditional standard of probit 9 mortality or the same numbers using sterility and the inability to fly as the criterion for acceptance are applicable. Since live, although sterile, insects will be present in many cases, quarantine concerns occur which will be addressed later in the discussion on operational needs.

2. Efficacy in the "trade situation" or the actual state found in commerce. The data produced must indicate the treatment will be efficacious (that is, all organisms are dead or sterile) in the most resistant life stages and physical surroundings found in trade. For example, eggs or larvae found in fruit; wood diseases found at the center of a log; disease organisms, fungal, bacterial or virus, in the stage expected, such as mycelial, spore or other.

3. Acceptability to industry. Measures developed and required must be operationally practical, economical and within reasonable expectations of modern techniques. However, quarantine security is the final determinant in accepting or rejecting a particular treatment or practice.

4. Supervision of treatments for regulatory objectives must provide

irrefutable evidence the treatment has been performed. The evidence may include documentation, indicator/dosimeters or other means.

The likelihood that live pests will exist and can be found on inspection or even later by the consumer or in traps is a major concern to quarantine authorities, including APHIS and various State Departments of Agriculture. Alternative means of addressing these concerns must be explored before quarantine treatments using irradiation will be fully accepted by USDA and our cooperators.

There is presently no field applicable method to identify pests or host produce as having been irradiated. In the absence of such tests are documentation or label type indicators adequate to negate further quarantine action when live pests are found after treatment? We are willing to consider the options available for certifying the treatment including data on the accuracy and use of indicators in the low range required. How confident can we be in the accuracy of the documentation available and how accurate are the indicators? We must be convinced that quarantine concerns are met and that all live pests of quarantine importance discovered on imported commodities in this country are indeed incapable of reproduction and therefore not a danger to U. S. agriculture. We can assure this will happen by insisting that data developed for approval of a treatment indicate that all individuals emerging will be sterile and that adult fruit flies in particular will not be capable of flight to avoid unnecessary quarantine action by preventing their appearance in traps; and that the means we use to verify the treatment are adequate.

We are confident that workshops such as this and continued dialogue with the industry and other resources provide important opportunities for us to work together to fully explore and find acceptable ways to address these issues.

In addition to the arthropod concerns most often addressed by this group, quarantine treatment needs exist for nematodes, various plant diseases, and the sterilization of noxious weed seeds. These appear to be areas in which irradiation may be asked to and can provide useful services.

James F. Fons
USDA, APHIS, PPQ

COMMENTS AND DISCUSSION ON POINTS RAISED BY JIM FONS USDA/APHIS/PPQ

Differentiating Smuggle Fruit from Irradiated Fruit

The point was made that regulators are always concerned about smuggled fruit. Since irradiated fruit may contain live larva, and there would be no way to determine the irradiated fruit from smuggled, non-treated fruit once it enters commerce. If regulators inspect such fruit and finds larva, they would have no alternative but to take regulatory action.

Hitchhikers

Hitchhikers are by far the biggest problem, and it was pointed out that an irradiator capable of handling a pallet load of fruit should also take care of hitchhikers. Regulations are developed to address both problems, quarantine pest and hitchhikers. Irradiation will not necessarily solve the problem with hitchhikers, because the main problem with hitchhiking insects are related to the way the containers are left open, particularly in yards under lights or in the packing facility. Even after the commodities have gone through the irradiator, you still need to safeguard them from reinfestation. Irradiating facilities must have sufficient storage space, cold storage space, etc. for the products before and after treatment.

Double Standard for Sterile Insect Release Program and Insects of Quarantine Interest

The point was made that in the sterile release program, PPQ does not demand the same probit 9 level of inviability; only 99.99 percent for sterile insects. The sterile release program operates under realistic guidelines whereas commodity treatment is somewhat more stringent. Irradiating a pallet load of produce or fruit, you operate under minimum and maximum doses. Most of the product on the pallet gets higher dose than the minimum; only a small fraction of the pallet gets the minimum dose. (Therefore, there should be no problem with sterility).

Comparison of Irradiation with the Pasteurization of Milk

Before a plant can pasteurize milk, a good quality control program must be in place. Otherwise people could be infected by all sorts of bacteria. Before pasteurization was accepted the dairy industry had all kinds of arguments that you will underpasteurize or overpasteurize the milk, and there's going to be (will be) some botulism from that. With minor exceptions, commercial pasteurization of milk is very safe. Irradiation as a quarantine treatment is being developed in a similar way, closely monitored, and can be equally as safe.

PPQ Statement on QA/QC

We have looked at scientists' systems approaches such as (QA/QC) with FSIS, and we have found that kind (type) of control is difficult for us with limited staff to monitor. What we have looked for in the past is a coup-de-grace, if we want to call it that, that assures us that the beast is dead.

...None of these things improve quality. Irradiation doesn't improve the quality of anything... shrimp doesn't get any better after it is rotten and irradiated... We have a relatively small staff with a limited charge... We need something that we can more readily see at the end, not try to go through the whole thing (process).

Inspectors at facilities

The point was made that the U. S. accepts mangoes from Mexico which have been treated by hot water, and there is an APHIS official in the facility to certify that treatment is done (properly). The assumption was made that similar APHIS officials would (could) be located at an irradiation facility. APHIS/PPQ stated that we could not assume APHIS personnel would have a person in the plant at all times. It may be necessary but that is something that needs to be decided. It was also pointed out that we have dosimetry (as a check) with irradiation that we do not have with hot water dip.

Incentives for Cheating with Irradiation

In the case of release program for sterile fruit flies, the government has control of the program from start to finish; all the work is done by government salaried employees; there are no benefits at all for cheating. It does not relate to whether or not the dosimetry works; it is merely the fact that there is no one to check to make sure no one cheats. In commercial applications, there is some incentive, in some cases, to cheat. How does one check for that. A comment was made that the same incentives for cheating is equally applicable to other treatment processes. (such as hot water dip).

Inspectors in facilities

...We in the U. S. should look at ourselves as sellers, and can we afford to have an inspector from Japan and Australia and every other country that we will ship into in our facilities just to be sure that we are doing the job that needs to be done? I have a lot of concern that the USDA will require an inspector (to) be in every facility. I think it could have a big backlash.

General Observations (Hawaii Representation)

I would like to make some general observations. One, I enjoyed this workshop very much, and I think we have (had) some very good discussions. I think that one group of people seem to be underrepresented here and that is the user, the industry people. ...we don't allow enough opportunity to educate the public and make answers. In other words, this is a good occasion that we could have invited the Hawaiian industry people to talk and learn more about the regulations and possible use of irradiation for quarantine treatment. So, that causes me to think that maybe we should be thinking about another conference on disinfestation of food and agricultural products by irradiation in Hawaii. ...I'll need to think about it some more and see if we have funds for one.

The last one (meeting to look at the dose level for irradiation of papayas), APHIS, ARS, and DOE contributed funds. It was successful in determining the minimum dose for treatment of papayas.

Regarding treatment of papayas, there is little benefit of using other than the minimum (dose) 0.15 Gy. Last year we finished a second study, a follow-up study on why irradiation would help delay ripening in papaya. It is not exactly that it would delay the climacteric, reaching of the climacteric peak of the papaya, but keeping the food firm for several days longer when it is irradiated at 0.75 kGy. In that sense, I think, if the papaya packer were to use irradiation for quarantine treatment, he actually has some choice about the dose, minimal dose of 0.15 kGy depending upon the max/min dose ratio; some would be higher. If the papaya packer were to ask me what goals I would suggest, I would say somewhere between 0.15 kGy and 0.75 kGy, as long as they do not exceed the maximum dose 1.0 kGy set by FDA.

So, with that, actually almost no fruit flies would emerge, but going back to 1988 when APHIS was publishing the proposal to allow the 0.15 kGy for papaya, there was one paragraph from a commentor who suggested that we raise the minimum dose for papayas from 15 krads (0.15 kGy) to 26 krads (0.26 kGy). At 0.15 kGy any fruit fly larvae that emerge as adults would have crumpled wings and be incapable of flight, and therefore incapable of spreading. The commentor suggest the dose of 0.26 kGy would ensure that no fruit fly larvae would even emerge..., and the percentage of marketable fruit thus be increased. ...No changes came from the comment. APHIS stated... "our responsibility is to prevent the spread of pests, and a policy has been to do so with treatment using the minimum dose necessary. By requiring a minimum dose of 0.15 kGy we are preventing emergence of fruit fly capable of reproduction, and are thus satisfying the quarantine requirements. Requiring a level of irradiation higher than 0.15 kGy would demand that papaya be irradiated for longer periods of time. This would involve a greater expense to the industry with no increase in protection..."

Statement by ARS

I don't think that we in ARS can all agree with everything that's in the book, and certainly (everything that's said) in (during) a meeting like this. It's your specific questions that APHIS wants to address after this meeting. ARS will look at those, as we have always done, and bring to bear the best scientists that we have available to us to look at those specific questions and give you such answers on those specific issues. I'm confused somewhat by some of the discussion here, ...that I hear from the industry that make irradiators. And then if we are talking about a quarantine problem mainly that has to do with import, except in the case of Hawaii, which has several commodities that they might be able to ship to us (U. S.) if they had irradiators and if they have approval (certification). But in most cases, we are not going to lose most exports because we do not have irradiation, because most of the ones (countries) that we use methyl bromide for, for instance, will not accept irradiation. Most of our problem is actually with imports that are going to come in.

For example, how are we going to address the problem in Chile with mites on grapes, with grapes that are too sensitive for irradiation? Mites are difficult to sterilize with irradiation. How is that going to work and are you intending to build an irradiator in Chile? What about mangos coming in? We certainly cannot accept mangos that have the mango seed weevil. The data is very confusing as to how much irradiation is needed to sterilize the mango seed weevil. It is quite difficult to run experiments when you do not have high infestation rates. Mango seed weevil is a problem in the Philippines or from Hawaii. These are problem for somewhere else (other countries).

We have our own problems, for example cherries going to Europe. We have to start treating cherries going to Europe because of the cherry fruit fly, and irradiation may play a part in that (quarantine treatment) conceivably could be an answer for us. But cherries going to Japan where we send 25% of our crops; Japan has categorically refused to accept irradiation.

I hear people wanting procedures for imports. How does the industry intend to address those import problems where normally the treatment has to be done in the country of origin.

Additional Remarks by
Mr. Mike Shannon
USDA/APHIS/PPQ

Representation of APHIS/PPQ had a list which illustrated the 12-14 major countries with whom APHIS currently carries out formal bilateral discussion on phytosanitary issues. The list shows the commodity and country that efforts are underway to gain market access. Another list illustrates the important pest issues which need resolving in order to gain market access, for example, potatoes, apples and sweet potatoes, etc. These requests come from the U.S. fruit and vegetable industries who have identified a market and are prepared to invest in export. Three areas where irradiation may be a viable solution are:

(1) Those markets which U. S. industry has explored and the problems which need resolving to gain market access; these should also include those commodities which we will loose export markets from the loss of methyl bromide.

(2) The export opportunities which we are not exploring simply because there is no quarantine treatment.

(3) Trade between the U.S. and Hawaii because it, too, is handled by regulation as if it were a foreign country.

The list is a record of most everything in which we have had discussions with U. S. trading partners. It will only serve as an indicator and should not be considered as a major measure. The list is more inclusive than just fruits and vegetables. The objective should be to identify those candidate commodities for radiation as a quarantine treatment.

Table 1 summarizes the results of this review.

Table 1

Commodity	Target Pest(s)
Apples (Wash. & Calif.)	Rhagoletis fireblight, appleworm, codling moth, plum, curculio
Blueberries	blueberry maggot, apple maggot, plum curculio
Calamodin Plants (soil only)	nematodes (?) phytophathora and pithiums Fruit flies
Cherries	Cherry maggot
Citrus	Fruit flies (Mex./Carib.)
Papaya	Fruit flies
Pears	Codling moth
Logs/ Lumber	
Hay	Hessian fly
Pine bark	pinewood nematode
Stone Fruit	
Potatoes	potato nematode
Tomatoes	leaf miners?
Walnuts	walnut curculio

[illegible]

[illegible] plum pudding [illegible]

[illegible] a foreign country [illegible]

[illegible] vegetables. The [illegible] should be [illegible]

Grand

Total

APPENDIXES

APPENDIX A

Irradiation Workshop Agenda

February 1 - 4, 1994
Cabot Lodge
Gainesville, Florida

Tuesday, February 1, 1994. . . . . Arrival/Check-in at hotel

Day One Wednesday, February 2, 1994

Session One - Moderator: Dr. Jennifer L. Sharp

8:00-8:10am	**Dr. Mary E. Carter** Welcome and Introduction
8:10-8:30am	**Dr. Kenneth Vick** Objectives & Charge of the Workshop
8:30-9:00am	**Dr. Paul Kuznesof** Irradiation as a Quarantine Treatment: The Role of the U.S. Food and Drug Administration
9:00-9:30am	**Ms. Connie Riherd** Approval Status of Irradiation as a Quarantine Treatment for Florida Commodities
9:30-10:00am	**Dr. Burrell Smittle** Linear Accelerator Irradiation as a Quarantine Treatment
10:00-10:30am	*Break*
10:30-11:00am	**Dr. Harry Farrar IV/Mr. Don Derr** Dose Assurance for Radiation Quarantine Treatments
11:00-Noon	**Mr. Paisan Loaharanu** International Perspective on the use of Irradiation for Quarantine Purposes
12:00-1:30pm	*Lunch*

Session Two - Moderator: Dr. Don Thayer

1:30-2:00pm	**Dr. James H. Moy/Dr. Lyle Wong** Current Interest in and Prospect for Adopting Irradiation as a Quarantine Treatment Procedure in Hawaii
2:00-2:30pm	**Dr. Guy Hallman/Dr. Jennifer Sharp** Overview of Effective Irradiation Doses for Fruit Flies and Other Arthropods for Quarantine
2:30-3:00pm	*Break*
3:00-3:30pm	**Ms. Michelle Marcotte** Suitability of Irradiation Disinfestation on Produce Previously deemed to be Unsuitable or Sensitive
3:30-4:00pm	**Dr. Roy McDonald** Effect of Irradiation on Quality of Horticultural Products
4:00-4:30pm	**Dr. Betsey Beckemeyer/ Dr. Mary Jo Hayes** Research Progress on Identifying Irradiated Insects
4:30-5:00pm	**Dr. Ralph Ross** Discussion & Summary: Day One

Day Two Thursday, February 3, 1994

Session One - Moderator: Dr. Peter Witherell

8:00-8:30am	**Dr. Joe Borsa** Technical and Economic Aspects of Gamma and Electron Irradiators for Grain and Other Commodities
8:30-9:00am	**Dr. James Nation** Research Progress on Identifying Irradiated Insects
9:00-9:30am	**Mr. Martin Stein** *Now for Something Completely Different*: The GRAY*STAR Option
9:30-10:00am	*Break*

10:00-11:00am	**Mr. Jim Fons** Update on APHIS Irradiation Quarantine Treatment Requirements
11:00-11:30am	**Discussion** Overview of Regulatory Issues
11:30-1:00pm	*Lunch*

Discussion Session - Moderator: Dr. Ralph Ross

1:00-4:00pm	Discussion of State of the Art, Identification of Knowledge Gaps, Research Priorities to Fill Gaps, and Conclusions
4:00-5:00pm	**Dr. Burrell Smittle**, Host Visit to view the Florida Department of Agriculture Linear Accelerator and Facility

APPENDIX B

List of Attendees
ARS/APHIS Workshop for Fruits and Vegetables
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February 1-3, 1994

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